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AMERICAN JOURNAL OF SCIENCE.

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FOURTH SERIES.

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WITH PLATE I.

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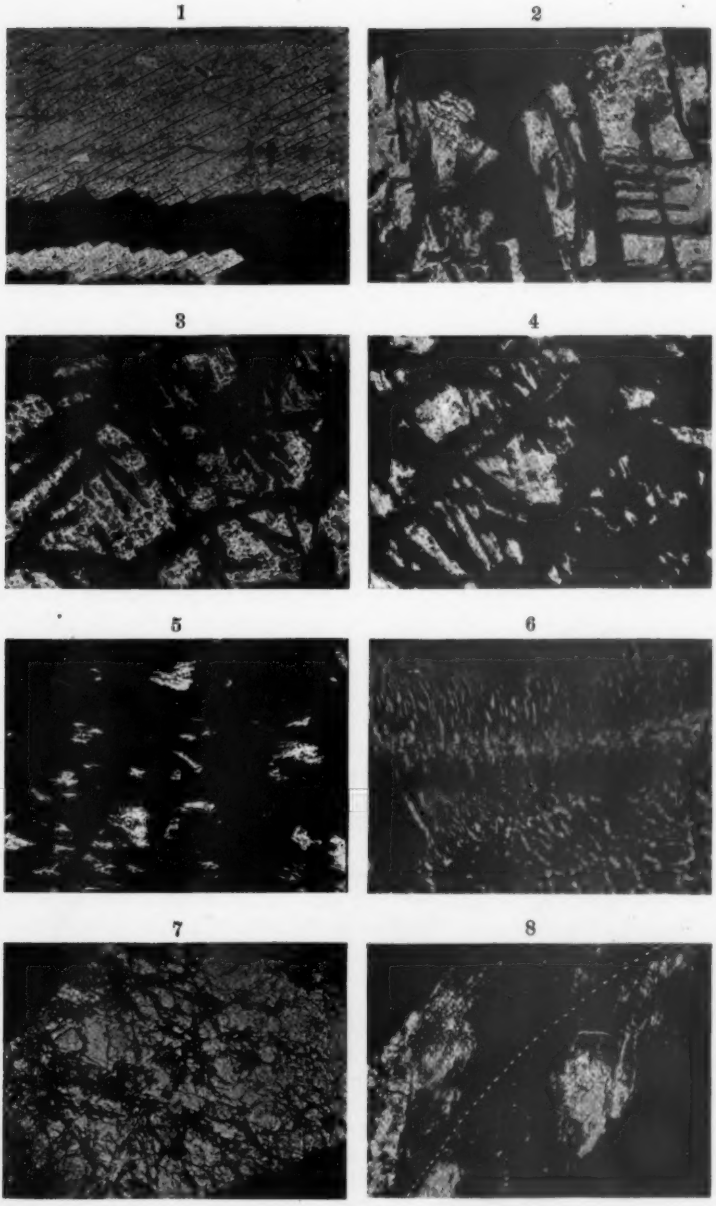


1. Original Albite (Mitchell Co.), ×10. 2. Fragment of same heated to 1200°, ×20. 3. Another fragment, 1206°, ×20. 4. Another, 1225°, ×20. 5. Another, 1250°, ×20. 6. Another (×300) four hours at 1125°. 7. Another, bent at 1200°, ×10. 8. Microcline bent at 1200°, ×10; note the direction of cleavage (cf. dotted line). All the photographs were made through crossed nicols, vitreous areas are therefore black.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. VII. — *The Isomorphism and Thermal Properties of the Feldspars;* by ARTHUR L. DAY and E. T. ALLEN. (With Plate I.)

THE investigation here recorded is the first chapter in a rather comprehensive plan for the study of the rock-forming minerals at the higher temperatures. In its broader outlines at least, it is by no means a new plan. Mr. Clarence King and Dr. George F. Becker were inspired by a desire to reach the mineral relations from the experimental side, which is recorded in the very earliest records of the U. S. Geological Survey, and much of the remarkable ground-breaking work of Professor Carl Barus was undertaken in furtherance of a carefully prepared scheme of research along these lines. The matter has been advanced but little in the intervening years. The present renewal of the effort in this direction is again due to Dr. Becker and has the benefit of his wide field experience and enthusiastic and effective coöperation throughout.

In October, 1900, one of the authors was called from the Reichsanstalt to equip a laboratory in the U. S. Geological Survey in which the exact methods and measurements of modern physics and physical chemistry should be applied to the minerals. The ultimate purpose was geological, to furnish a better basis of fact for the discussion of the larger problems of geology, but it appeared highly probable also that a quantitative study of the thermal phenomena in this class of substances would offer new relations of intrinsic interest and of considerable theoretical value. This inference has been happily substantiated quite recently through the publication by Tammann of an extended treatise on melting and crystallization,* in which

* Tammann, "Krystallisiren und Schmelzen." Leipzig, 1903.

he offers some very interesting speculations on the conditions of equilibrium for substances above and below the melting temperature under different pressures. The behavior of crystalline minerals, which melt at temperatures considerably higher than he was able to command, offers peculiarly advantageous opportunities for verifying the truth of his inferences and of contributing further to the knowledge of this most important change of state of matter.

Temperature Measurements.—It is only a short time since it became possible to measure even moderately high temperatures with certainty and to express them in terms of a well-established scale. Temperature is a peculiar function in that it is not additive. Two bodies, each at a temperature of 50°, can not be united to obtain a temperature of 100°, nor can any number of bodies, at a temperature of 50° or below, give us information about the temperature 51° or above. Furthermore, temperature is not independently measurable: we can only measure phenomena like the expansion of gases or the conductivity of platinum wire or the energy of thermal radiation, which we have good reason to suppose will vary with the temperature uniformly or according to a known law.

The measure of temperature now generally accepted as standard is the expansion of hydrogen gas between the melting point of ice and the normal boiling point of water, divided into 100 equal increments or degrees. Temperatures above this point* have been determined by continuing the expansion of hydrogen or nitrogen in the same units, as far as it has been found possible to provide satisfactory containing vessels for the expanding gas. Such determinations are then rendered permanent and available for general use by establishing fixed points, such as the melting temperatures of easily obtainable pure metals, at convenient intervals. Beyond 1150° no trustworthy gas measurements have been made and we have therefore no standard scale. For higher temperatures it is usual to select some convenient phenomenon which is measurable up to the temperature desired, to compare it with the gas scale as far as the latter extends and then to continue on the assumption that the law of its apparent progression below 1150° will continue to hold above that point. In this way we obtain degrees which, if not identical with the degrees of the gas scale, approximate very closely to them and can receive a small correction if necessary, whenever the gas scale shall be extended or another scale substituted.

* To 600°, Chappuis et Harker, Travaux et mémoires du bureau international des poids et mesures, xii, 1902. To 1150°, Holborn and Day, Ann. der Physik, ii, 505, 1900; English translation, this Journal [4], x, 171, 1900.

The application of measurable high pressures at the higher temperatures has never been successfully accomplished, and until something can be done in this direction, our knowledge of the rock-forming minerals and in fact all the generalizations relating to equilibrium between the states of matter, which have been established for moderate temperatures, must be regarded as more or tess tentative and subject to eventual revision. We have been accustomed to assume, both in geology and physics, with rather more confidence than scientific experience justifies, that established relations for ordinary temperatures and pressures will hold in comparable ratio for the higher temperatures and pressures also. Experimentation under extreme conditions is slow and technically difficult, and it is therefore not strange that simple relations which are verifiable within easily accessible conditions should now and then be accorded the dignity of natural laws without sufficient inquiry into the more remote conditions.

General Plan.—Our plan on entering this field was to study the thermal behavior of some of the simple rock-making minerals by a trustworthy method, then the conditions of equilibrium for simple combinations of these, and thus to reach a sound basis for the study of rock formation or differentiation from the magma. Eventually, when we are able to vary the pressure with the temperature over considerable ranges, our knowledge of the rock-forming minerals should become sufficient to enable us to classify many of the earth-making processes in their proper place with the quantitative physico-chemical reactions of the laboratory.

Relation to Geological Research.—The relation which this plan bears to general geological research may perhaps be expressed in this way. Geological field research is essentially a study of natural end-phenomena, of completed reactions, with but a very imperfect record of the earlier intermediate steps in the earth-making processes. The records of the splendid laboratory experiments in rock synthesis which have already been made are also of this character. The final product has been carefully studied, but the temperatures at which particular minerals have separated out of the artificial magma, and the conditions of equilibrium before and after such separation, have not been determined. In fact, except for a limited number of determinations of the melting points of natural minerals, no exact thermal measurements upon minerals or cooling magmas have been made, and it is in this direction that a beginning is to be attempted. The temperatures of mineral reactions under atmospheric pressures are nearly all within reach of existing laboratory apparatus and methods.

Existing Methods.—Furthermore, the methods which have been used in determining these mineral melting points seem to the authors to be open to serious objection both in principle and in application. They depend, almost without exception, upon the personal judgment of the observer and not upon the actual measurement of any physical constant. For this reason perhaps more than any other, the results obtained by different observers upon the same mineral from the same source do not agree within considerable limits, much larger than can be properly ascribed to impurities in the specimens. Familiar examples will best illustrate this point. Among the determinations of the mineral melting points, two have received much more general acceptance than others;—those of Joly* and of Doelter.†

The melting temperatures which they obtained for some of the typical feldspars are as follows:

	Meldometer Measurement.		Thermoelectric Measurement.	
	Joly, 1891;	Cusack, 1896.	Gas Furnace. Doelter, 1901.	Electric Furnace Doelter, 1902.
Microcline	1175°	1169°	1155°	1155°
Albite	1175	1172	1103	1110
Oligoclase	1220		1110	1120
Labradorite	1230	1235	1119	1125
Anorthite			1110	1132

The determinations agree in recording higher melting points toward the calcic end of the series, but the differences between corresponding melting points by the two methods is greater than the observed differences between different feldspars.

Joly's method was novel. He stretched a thin strip of carefully prepared platinum foil between suitable clamps, placed a few grains of the powdered mineral upon it and mounted a small microscope above, so as to be readily trained on any part of the strip. The foil was then heated by an electric current which could be very gradually increased, and the temperature measured from the linear expansion of the strip at the moment when the observer at the microscope noticed the first signs of melting. The author of this method was able to obtain concordant results with it to within about 5° C., but differences several times greater than 5° appeared in the observations made by one of us‡ with the Joly apparatus, unless the grains were prepared with the greatest care and all the observations made by the same observer. The size and form of the grains, the care used in locating them exactly in the middle of the

* J. Joly, Proc. Royal Irish Acad., iii, 2, p. 38, 1891. R. Cusack, Proc. Royal Irish Acad., iii, 4, p. 399, 1896.

† C. Doelter, Tschermak, Min. u. Petr. Mitth., xx, p. 210, 1901; xxi, p. 23, 1902.

‡ Day.

strip, every draught of air, but most of all the judgment of the observer as to when the substance appeared to melt, all entered into the result to a very considerable degree. And there is another source of error with which we afterward became familiar, which may serve to account for the very large differences between Joly's results and our own later values with some of the well-known minerals, though not with all. In certain of the minerals, after melting, the resistance to change of shape due to viscosity is of the same order of magnitude as that due to the rigidity of the crystal just before melting, a fact which may well have led to large errors of judgment in this method of detecting melting points.

The possibility of working very expeditiously with minute quantities of a substance led us to study this method with great care, and we were fortunate enough to possess an instrument of Prof. Joly's own model made by Yeates & Son, Dublin, but the results obtained with it, even under most favorable conditions, are more in the nature of personal estimates than of exact measurements of the change of state. Its value for qualitative study, and in cases where only a very minute quantity of a substance is available, is unquestioned.

Doelter has employed electric furnaces modeled after that in use at the Reichsanstalt by Holborn and Day for the determination of the melting points of the metals, measured his temperatures with thermoelements, and used several grams of material in his determinations, but he also judged of the approach of the melting point by the appearance of the charge and usually recorded two temperatures, the first approach of viscous melting, and the point where the material appeared to become a thin liquid.

Detailed Plan.—We determined from the first to get rid of this personal factor. However carefully such observations may be made, and however well supported by the reputation of a particular scientist for skillful and exact work, they can not have a permanent value. Melting points of pure minerals are not different, in principle at least, from the melting points of other chemical compounds or of metals. They occur at less accessible temperatures and involve some complicating phenomena, as we shall see presently, but the change of state of a solid crystalline mineral to a liquid must of course be defined by an absorption of heat. Whether the appearance of the mineral charge in the furnace will offer a trustworthy index through which to locate this absorption, may well be expected to differ with different substances. Nearly all observers have recorded the fact that many substances of this class remain very viscous after melting and that the transition is not well marked in the appearance of the material.

We therefore planned an apparatus* which should be as sensitive as possible to heat changes over a long range of temperatures, and then prepared to examine the thermal behavior of simple minerals of natural or artificial composition when gradually heated or cooled. Changes of crystalline form (Umwandlungen) or of state (melting and solidifying) must involve a more or less sharply marked absorption or release of heat and be recorded as breaks in a smooth curve in the same way as in the determination of metal melting points or the singularities of any of the well-known chemical compounds at lower temperatures.

First Group of Minerals Investigated.—The particular group of minerals chosen for the first investigation was the soda-lime feldspar series, and orthoclase (microcline). The reasons for this choice will be fairly obvious. Aside from its being altogether the most important group of rock-forming minerals, unusual interest has been attracted to it through Tschermak's theory that these feldspars bear a very simple relation to one another, that they are (orthoclase excepted of course) in fact merely isomorphous mixtures of albite and anorthite. This hypothesis has given occasion for serious and extended study both from the optical and thermal sides.

A complete review of the literature of the feldspars will not be attempted here. Although opinion is still somewhat divided,† it is probably fair to say that the optical researches have failed definitely to establish or disestablish the isomorphism of the albite-anorthite group, and that it is somewhat uncertain whether conclusive evidence will be obtained by optical means alone. Investigation from the thermal point of view has been even less satisfactory by reason of the subjective methods employed, to which reference has already been made, though the recorded results indicate with reasonable unanimity that the melting point of anorthite is above that of albite and that the intermediate feldspars will probably fall between the two.‡ Beyond this conclusion, the great body of evidence is more or less contradictory and sometimes controversial in character.

Orthoclase (preliminary).—Somewhat unluckily, our measurements began with natural orthoclase (microcline) from

* For a detailed description of this apparatus see Day and Allen, Phys. Rev., xix, p. 177, 1904.

† Fouqué et Lévy, Synthèse des Minéraux et des Roches, p. 145, 1882. C. Viola, Tschermak's Min. u. Petr. Mitth., xx, p. 199, 1901. Lane, Journ. Geol. XII, ii, p. 83, 1904. J. H. L. Vogt — Die Silikatschmelzlösungen. Christiania, 1903.

‡ J. H. L. Vogt, loc. cit., p. 154, expresses the opinion that the soda-lime feldspars will be found to fall under Type III of Roozeboom's types of isomorphous series, with a minimum between anorthite and albite. (See p. 134, seq.)

Mitchell Co., North Carolina, a quantity of which was placed at our disposal by the U. S. National Museum. The material was powdered so as to pass readily through a 100-mesh sieve, and placed in 100^{cc} or 125^{cc} platinum crucibles, sometimes open and sometimes covered, in charges of from 100 to 150 grams. These charges were heated slowly in the electric furnace from 600° to above 1400° C., but, although the thermal apparatus was sufficiently sensitive to detect an unsteadiness of a tenth of a degree with certainty, not the slightest trace of an absorption or release of heat was found. The charge at the beginning of the heating was a dry crystalline powder, which was prodded from time to time with a stout platinum wire to ascertain its condition as the heating progressed. At about 1000° traces of sintering were evident, at 1075° it had formed a solid cake which resisted the wire, at 1150° this cake had softened sufficiently to yield to continued pressure and at 1300° it had become a viscous liquid which could be drawn out in glassy, almost opaque threads by the wire. Under the microscope the opacity was seen to be due to fine, included bubbles, the material being entirely vitreous. The cooling was equally uninstructive; the vitreous mass solidified gradually without recrystallization or the appearance of any thermal phenomenon. Frequent repetition with fresh charges and varied conditions added nothing to our knowledge of the melting temperature, and the matter began to look very unpromising.

We also reheated charges of the resulting glass which was sometimes repowdered and sometimes in the cake as it had cooled. But except to observe that the glass powder began to sinter earlier (800°), no new facts appeared.*

Then we tried by various means to recrystallize the melted orthoclase. We mixed crystalline powder with the glass, we applied successive quick shocks to the cooling liquid for several hours with an electric hammer below the crucible, we varied the rate of cooling and even tried rapid see-sawing between 800° and 1300°. We circulated air, water vapor, and carbonic dioxide through the charge throughout the heating, and finally introduced a rapid alternating current sent directly through the substance while cooling, but no trace of crystallization resulted. An extremely viscous, inert mass always remained which gradually hardened into a more or less opaque glass. It appeared somewhat translucent if very high temperatures had been reached, but was never clear.

Following orthoclase, a number of specimens of natural albite were tried under similar conditions and with entirely similar results.

* These sintering temperatures varied within considerable limits with the fineness of the material and therefore serve only in a very rough way to define the state of the charges.

Later on, when more experience had been acquired, these minerals were taken up again and a satisfactory explanation for their behavior was found. But for the moment all the defining phenomena appeared to be so effectively veiled by some property, presumably the viscosity, that we were constrained to look about for some simpler compound which should give us a better insight into the behavior of mineral glasses and their thermal relations, and to lay aside the feldspars until they could be more successfully handled.

This outline of our unsuccessful experiences is given here in some detail, in order to show the actual difficulties which confront the student in working with the feldspars, in the face of which it is certainly not surprising that uncertain and contradictory conclusions have been reached.

Borax.—The substance chosen for this preliminary work was ordinary anhydrous borax (sodium tetraborate). We chose this merely because it was a simple glass and unlikely to undergo chemical change. It is easily obtainable pure and its thermal phenomena are within easy reach. The study of borax proved to be most instructive. It gave us an effective insight into the behavior of this class of substances, and in particular served to define the phenomena of melting and solidifying in substances which undergo extreme undercooling and which recrystallize with difficulty or not at all. The results of this study of borax were therefore of much interest in themselves and were given in a paper before the National Academy of Sciences at its spring meeting in Washington last year (April 21, 1903), but were not printed at that time.

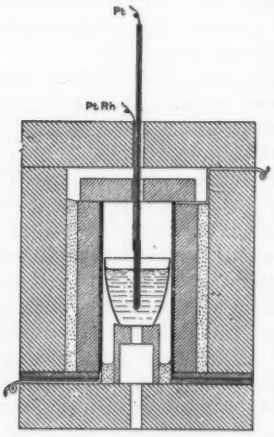


FIG. 1.

The borax glass upon which our measurements were made was prepared in the usual way by heating the crystals until the water of crystallization had been driven off and the viscous mass was reasonably free from bubbles. If the borax is pure, the anhydrous product, when cooled, is a brilliant, colorless glass, isotropic, of conchoidal fracture, and specific gravity 2·37. The specific gravity was determined in the fraction of kerosene boiling above 185° C. About 100 gr. of this glass were then broken up and placed in a platinum crucible in the electric furnace. The thermoelement was placed in position

as indicated in fig. 1, the heating current properly regulated and observations of the temperature made at intervals of one minute, while the glass softened and passed gradually over into a thin liquid (800°). Then the current was reduced and the cooling curve observed in the same way. These observations gave an unbroken curve both for the heating and cooling, as in the case of all the glasses,* without a definite melting or

FIG. 2.

solidifying point, although the arrangements for detecting an absorption or release of heat were very sensitive. Prodding at intervals with a platinum rod showed the change to be perfectly gradual from a clear, hard cake through all degrees of viscosity to a fairly thin liquid and back again. This observation is of considerable interest as showing that the absence of bounding phenomena between the cold glass which fulfils the mechanical conditions for a solid very perfectly, and the liquid, is not confined to mixtures of complicated chemical composition, but is exhibited also by true chemical compounds of undoubted purity. It is therefore not conditioned by composition but by the physical nature of the substance. Having verified this behavior of anhydrous borax by several repetitions of the experiment, various disturbing influences were applied to the slowly cooling liquid in the hope that some temperature

* See Tammann, loc. cit., also Roozeboom "Die heterogenen Gleichgewichte, etc." Braunschweig, 1901.

or range of temperature would be found within which the vitreous condition would prove unstable and crystallization be precipitated. The jar produced by an electric hammer pounding upon the outside of the furnace during cooling proved to be sufficient to bring down the entire charge as a beautiful crystalline mass of radial, fibrous structure, brilliant luster, rather high refractive index and increased volume. The photograph (fig. 2) will give some idea of the appearance of the anhydrous crystalline borax in the crucible. Its specific gravity proved to be 2·28 as compared with 2·37 for the glass, a

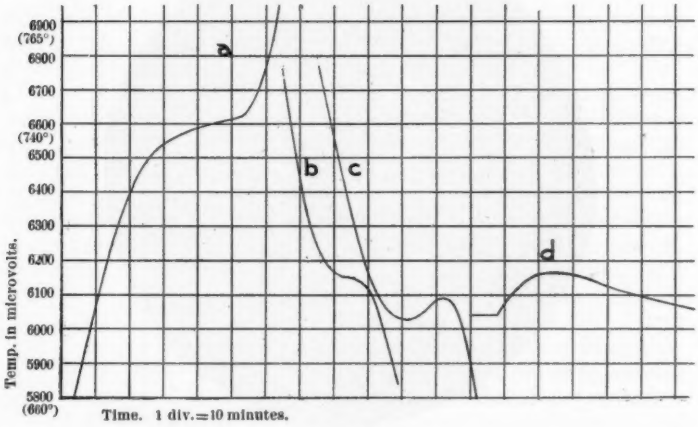


FIG. 3.

somewhat unusual relation,* which may in part account for the quasi-stability of the vitreous form during cooling.

Observations were then undertaken upon the crystalline borax with a thermoelement as before, to determine the melting temperature and solid modifications if such existed, but none of the latter were found. The charge melted uniformly at 742° and the melting point was well defined. A curve showing the minute-to-minute observations on the crystalline borax between the temperatures 660° and 765° is shown in the adjoining figure (fig. 3, *a*).

Having determined the melting point of crystalline anhydrous borax satisfactorily, we examined more closely into the conditions under which it solidified. As has been said, if the melted charge was allowed to cool slowly, undisturbed, no return to the crystalline state occurred. It merely thickened into a transparent glass without releasing the "latent" heat which it

* Tammann. Loc. cit., p. 47 et seq.

had taken on in melting (fig. 5, *b*). If it was subjected to the jarring produced by the electric hammer on the furnace wall, it cooled down a few degrees below the melting point and then began to crystallize, the heat of fusion was set free and a rise in temperature or hump immediately appeared upon the cooling curve as shown in the figure (fig. 3, *b*, *c*, *d*). Up to this point the phenomenon differs but little from the usual behavior of liquids which undercool in solidifying. We then varied the experiment by first cooling quietly to about 100° below the melting point and then introducing a few crystal fragments or starting the pounding. Crystallization and release of the latent heat followed at once. In fact over a range of some 250° immediately below the melting point it proved to be within our power to precipitate the crystallization of the undercooled mass entirely at will. It was even possible to cool the melted charge quietly down to the temperature of the room and remove it from the furnace as a clear glass, then, on a subsequent day, to reheat to some point in this sensitive zone and pound judiciously, when crystallization would at once begin, marked by the release of the latent heat of the previous fusion as before (fig. 4, *a* and *b*). The accompanying curves show the situation clearly. Curves *aa'* and *bb'* (fig. 5), were obtained from charges of crystalline and vitreous borax, respectively, of exactly equal weight, which were cooled and reheated in the same electric furnace under like conditions. The radiation from the furnace for like temperature conditions will also be practically the same, so that the more rapid rate of cooling and of reheating in the crystalline charge indicates a much smaller specific heat than for the vitreous form.

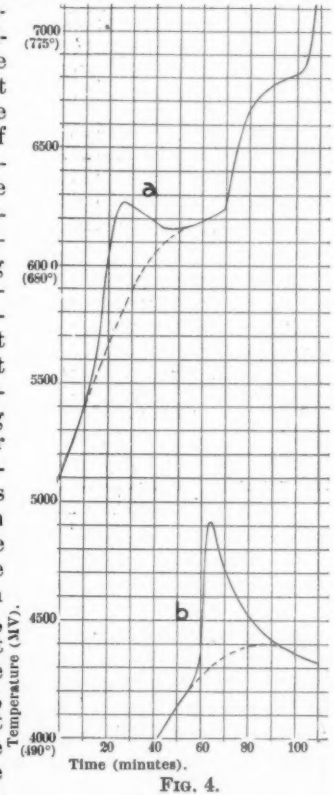


FIG. 4.

From the point of view of the usual definition of the solidifying point of a substance, a difficulty confronts us here: (1)

we were able to vary the beginning of solidification (crystallization) at will over a range of 250°, and (2) the temperature to which the charge rose after the undercooled liquid had begun to crystallize did not reach the melting point although once crystallization was induced only 10° below it in a furnace of constant temperature. The rapidity with which the crystallization and the accompanying release of the latent heat go on, depends in part upon the rate of cooling and the character of the disturbance which has been applied, i. e., upon accidental rather than characteristic conditions. It thus happens that the amount of the heat of fusion and its slow rate of liberation in the case of liquids which can be greatly undercooled and become very viscous, may be such as to deprive it of its usual significance as defining a solidifying point. It is, of course, a consequence of the phase rule that the solidifying temperature of an undercooled liquid is established, if only equilibrium between solid and liquid (and vapor) is reached before complete solidification is accomplished, but equilibrium *is not necessarily attained* during solidification, and the devices usually employed (sowing with crystals, agitating) are often totally inadequate to bring it about. The temperature to which a crystallizing liquid rises after undercooling is not necessarily constant or in any way related to the melting point, and is therefore not, in general, entitled to be regarded as a physical constant.

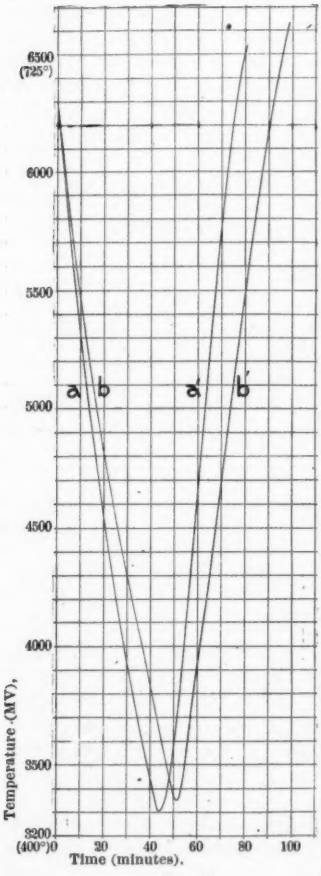


FIG. 5.

We then endeavored to ascertain whether the unstable domain had a lower limit also. For this purpose we mixed a quantity of the crystals with the glass and powdered them together to about the fineness represented by a 150-mesh sieve and heated them very slowly. In this condition the glass proved to be very unstable and crystallized readily with a rapid release of its latent heat at about 490°. Very slow heat-

ing (10 min. per 1°) gave a temperature a few degrees lower, but such variations as could be applied within the period of a working day did not suffice, under the most favorable conditions, to change this temperature materially. The first evidence of molecular mobility in borax glass, shown in the sticking together of the finest particles (sintering), and the first traces of crystallization and release of latent heat, appeared consistently at about 490–500°. Still a third phenomenon attracted our attention to this temperature. On every occasion when borax glass was heated rapidly, either powdered or in the solid block, a slight but persistent absorption of heat appeared in this same region and continued over some 20°, after which the original rate of heating returned. We were entirely unable to explain an *absorption* of heat in an amorphous substance under these conditions except by assuming an actual change of state to exist between amorphous glass and its melt, in which case the absorbed heat would reappear somewhere upon the corresponding cooling curve,—which it failed to do. We then reasoned that any assumed change in the molecular structure which would account for an absorption of heat would also be likely to cause an interruption in the continuity of the curve of electrical conductivity, and the relative conductivity was determined throughout this region; but no such interruption appeared.

Finally the matter was abandoned. The evidence did not appear sufficient to establish any discontinuity in the cooling curve of the glass, so long as no crystallization took place.

When these relations had been clearly established, we turned again to the feldspars.

It became clear very early in the investigation that only artificially prepared and chemically pure specimens would be adequate for our purpose. Each of the end members of the series, anorthite and albite, as found in nature, is always intermixed with some quantity of the other, while the intermediate members generally contain iron and potash, and all are liable to inclusions.

There was nothing new in this plan: Fouqué and Lévy* had demonstrated the possibility of making pure feldspars by chemical synthesis and had studied their optical properties some years ago. We undertook to prepare much larger quantities than they (200 grams), and to make a careful study of their heating and cooling curves under atmospheric pressure, the conditions under which anorthite and the plagioclases crystallize, the relations between the amorphous and crystalline forms, the sintering of crystalline and vitreous powders, in short, their entire thermal behavior, as we had done with the borax. At the same time it was our purpose to make

* Synthèse des Minéraux et des Roches, loc. cit.

careful determinations of the specific gravities of both the vitreous and the crystalline products, analyses of such portions as might be of special interest, and also to prepare microscopic sections wherever they were likely to throw light on the relations involved. The latter, after preliminary examination, were very thoroughly studied by Prof. J. P. Iddings of the University of Chicago, whose large petrographic experience with mineral crystallites makes his judgment of exceptional value.*

The constituents used in our syntheses were precipitated calcium carbonate, anhydrous sodium carbonate, powdered quartz (selected crystals) and alumina prepared by the decomposition of ammonium alum. None of these contained more than traces of impurities, if we except the quartz, in which 0·25 per cent of residue, chiefly oxide of iron, was found after treatment with hydrofluoric and sulphuric acids. All but the calcium carbonate were carefully calcined and cooled in a desiccator before weighing. To obtain a homogeneous product, the weighed constituents were mixed as thoroughly as possible mechanically, and heated in large covered platinum crucibles (100^{cc} capacity) in a Fletcher gas furnace.† After some hours heating, during which the temperature usually reached 1500° or more, the product was removed from the furnace, cracked out of the crucibles, powdered, passed through a "100-mesh" sieve and then melted again. This process probably gives a fairly homogeneous mixture, though a third fusion in the resistance furnace was generally made before determining the constants.

We prepared in this way albite (Ab), anorthite (An) and the following mixtures of the two: Ab_1An_5, Ab_1An_2, Ab_1An_1, Ab_2An_1, Ab_3An_1, Ab_4An_1. All of these were obtained in wholly or partially crystalline form, by crystallization from the melt, except albite. The syntheses were controlled by analyses of a number of the products, the results of which are appended.

ANALYSES OF ARTIFICIAL FELDSPARS.

	An		Ab_1An_5		Ab_1An_2		Ab_2An_1	
	Found.	Calculated.	Found.	Calculated.	Found.	Calculated.	Found.	Calculated.
SiO_2	43·33	43·28	47·10	47·18	51·06	51·30	60·01	59·81
Al_2O_3	36·21	36·63	34·23	34·00	31·50	31·21	24·95	25·47
Fe_2O_3	·29	....	·15	....	·22	....	·29	....
CaO	20·06	20·09	17·00	16·93	13·65	13·68	7·09	6·98
Na_2O	·11	....	1·74	1·87	3·68	3·79	7·79	7·73
	100·00		100·22		100·11		100·13	

* See Pt. II of the complete paper, Publications of the Carnegie Institution of Washington.

† Buffalo Dental Company, No. 41A. A Fletcher furnace of this type, with ordinary city gas pressure and a small blast motor, will melt all of the feldspars.

Anorthite.—Of the whole series of feldspars, this member is in many respects the simplest to deal with. It is of relatively low viscosity when melted and crystallizes easily, very rapidly, and always in large, well developed crystals. A 100-gram charge crystallized completely in ten minutes. Sudden chilling gave a beautiful clear glass entirely free from bubbles, somewhat slower cooling usually resulted in a partial crystallization from few nuclei, the crystals being always large. In appearance it resembles the natural mineral in every respect. Its hardness is also equal to that of natural anorthite. Thin sections show good cleavage, and twinning according to the albite law is frequent. The extinction and other microscopic characteristics are as well marked as in natural specimens.

The heating curve of crystalline anorthite is perfectly smooth except for the single break which marks the melting point. No trace of a second crystalline form (Umwandlung) appeared in this or any other of the feldspars within the temperature range of the observations (300°–1600°). Some undercooling always occurs in solidification even if the rate of cooling is slow, but it is less, under like conditions, with anorthite, than with any other member of the series. The heating curve of the glass shows a strong evolution of heat which may occur as low as 700°, when crystallization takes place. The melting point of crystalline anorthite was determined by three different thermoelements upon two different mineral preparations. It will be seen from the appended table that the determinations agree remarkably well.

ANORTHITE.

Date.	Element.	E. M. F. in MV.	Temperature.	Remarks.
First Preparation.				
Oct. 7, 1903	A	15939	1534°	solid charge, open crucible.
" " "	A	15914	1532	" "
" 10 "	A	15878	1530	covered crucible.
" " "	No. 3	16074	1533	" "
" " "	3	16058	1532	" "
" " "	3	16068	1532	" "
" " "	2	16095	1532	" "
		Mean	1532°	
Second Preparation.				
Jan. 16, 1904	A	15860	1532°	covered crucible.
" " "	A	15864	1532	
" 20 "	No. 3	15960	1533	
" " "	2	16102	1532	
" " "	2	16092	1532	
Mch. 31 "	3	15932	1531	1st & 2d preparations together.
		Mean	1532°	
				Melting temperature 1532°.

The close agreement of these determinations is of very considerable significance with reference to the method of temperature measurement employed. It will be remembered that the established temperature scale ends at 1150° and that temperatures beyond that point are extrapolated with the help of some trustworthy phenomenon which varies with the temperature. We chose for this purpose the thermoelectric force developed between pure platinum and platinum alloyed with 10 per cent of rhodium. Now the constants of such thermoelements will usually differ among themselves and require to be determined for each element by calibration with the gas thermometer or with the melting points of the metals.* It therefore offers an excellent test of the value of the extrapolation if some sharp melting point can be found in the extrapolated range to serve as a point of reference, The melting point of crystalline anorthite serves this purpose exceedingly well, and separate determinations of it with three separate thermoelectric systems gave identical values within the limits of error of observation. Our confidence that the extrapolation for these 375° is reasonably correct would therefore appear to be justified. Until the gas scale can be extended over this range, the melting point of pure anorthite (1532°) determined in this way will serve as a useful point in thermometry.

Ab_1An_6.—This feldspar decidedly resembles anorthite in its relatively low viscosity, the readiness with which it crystallizes, the well marked break in the heating curve at the melting point, and in its tendency to form comparatively large crystals. In general we may say that all these characteristics are somewhat less marked than in anorthite. Our determinations of the melting temperature follow:

AB_1AN_6

Date.	Element.	Electromotive Force in MV.	Temperature.	Remarks.
		First Preparation.		
Dec. 9, 1903	A	15501	1504°	slow heating.
" 11, "	A	15363	1493	rapid "
" 11, "	No. 3	15507	1498	" "
" 12, "	3	15599	1505	" "
" " "	3	15594	1505	" "
" " "	3	15604	1506	slow "
" " "	A	15518	1505	" "
			Mean 1502°	
		Second Preparation.		
Apr. 9, 1904	No. 3	15520	1499	slow heating.
" " "	2	15637	1497	" "
			Mean 1498°.	
			Melting temperature 1500°.	

* Day and Allen, loc. cit.

In one instance, while cooling the molten mass at a rapid rate, we obtained a result which has a most important bearing on the relation of the feldspars to one another, which will be referred to again in the concluding discussion of the experimental data. When the charge had cooled, it was found to consist of a compact mass of rather large crystals, radial in structure, at the bottom of the crucible (fig. 6), and a beautiful, transparent glass above. It was easy to separate the crystalline portion from the glass and to analyze the two separately. The composition of the two portions is practically identical, save for a slightly higher percentage of iron in the crystals.* In harmony with this latter circumstance the color of the crystals was a decided amethyst brown, while the glass was but slightly tinted. The analyses follow:

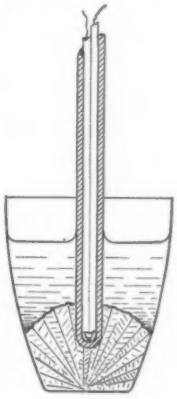


FIG. 6.

AB_1AN_5

	Glass Residue Found.	Crystalline Cake Found.
SiO_2	47·46	47·34
Al_2O_3	33·56	33·51
Fe_2O_3	·29	·47
CaO	16·99	16·84
Na_2O	1·87	1·89
	100·17	100·05

It is at once clear from these determinations that the solid phase has the same composition as the liquid phase, so far as it is within the power of chemical analysis to establish it.

Ab_1An_2.—In this feldspar we observe the same characteristics as in the two preceding, but they are still less sharply marked. The viscosity is greater, both solidification and melting take place more slowly, and the undercooling is so persistent that the furnace must be cooled slowly or the charge will come out wholly or partly vitreous.

* A small quantity of iron was contained in the quartz used in preparing the feldspars.

AB_1AN_2.

First Preparation.

Date.	Element.	E. M. F. in MV.	Temperature.	Remarks.
Oct. 16, 1903	A	14895	1459°	rapid heating.
" " "	No. 3	15142	1460	slow "
" 21 "	3	15101	1457	rapid "
" " "	3	15220	1466	extremely slow heating.
" 22 "	3	15204	1465	rapid heating.
" " "	3	15160	1462	
Dec. 15 "	3	15116	1467	powdered charge, open crucible.
" " "	3	15103	1466	ditto, slower.
" 16 "	3	15109	1467	solid cake, covered.
" " "	3	15044	1462	very fast.
" " "	3	15040	1462	same slower.
" " "	A	15035	1467	

Mean 1463°

Second Preparation.

Feb. 19, 1904	A	14945	1460°	covered, slow.
" 20 "	No. 3	15096	1466	ditto, faster.
" 25 "	2	15239	1467	fast.

Mean 1464°

Melting temperature 1463°.

Here again we made an attempt to discover a possible difference in composition in the first portions to crystallize out of the melt, this time by optical means. We first cooled the charge so rapidly that only a relatively small portion crystallized out in fine, reddish-brown spherulites at the surface and near the wall of the crucible. Without disturbing these, the crucible was then replaced in the furnace and slowly reheated until (about 5 hours) the remaining vitreous material had also become completely crystallized. Upon removing from the furnace, the charge presented a singular appearance. The reddish-brown stars remained undisturbed, while the later crystals were perfectly white. But though so different in appearance, the microscopic examination of slides cut from the different portions showed the two to be optically identical.

We have here another instance of the tendency of the iron to concentrate in the crystals which first form, a tendency which was frequently noticed throughout our work. It also appeared to matter little whether the first crystals formed at the surface or at the bottom of the charge. It is possible that this phenomenon may have significance in ore deposition, but we have not thus far been able to give it adequate attention.

Ab_1An_1.—With this member of the feldspar group a difficulty in effecting crystallization in the molten mass becomes noticeable. Undercooling will continue until the vitreous melt becomes rigid, unless the cooling is slow or some special effort in the way of mechanical disturbance or the introduction of nuclei is applied. Furthermore, when once precipitated, crystal formation goes on slowly, even when the charge is finely powdered, and the crystals are always small. Of the feldspars at least it is possible to say that the size of individual crystals varied chiefly with the viscosity; the thinner, calcic feldspars always gave large individuals, while Ab_1An_1, Ab_2An_1, Ab_3An_1 and Ab_4An_1 crystallized in closely interwoven, increasingly smaller fibers, which gave much difficulty in microscopic study. In comparison with this apparent effect of the viscosity, the rate of cooling was altogether insignificant in determining the size of individual crystals.

Several days were required to complete the crystallization of 100 grams of Ab_1An_1 under the most favorable conditions which we were able to bring to bear upon it. The melting temperature of the crystalline feldspar was still fairly well marked, however, and crystallization began in the powdered vitreous material as low as 700°. The melting point of this feldspar is:

AB_1AN_1.

Date.	Element.	E. M. F. in MV.	Temperature.	Remarks.
Feb. 9, 1904	A	14402	1416°	covered charge, heating rapid.
" 9, "	A	14400	1416	
" 10, "	No. 3	14529	1421	very rapid.
" 12, "	2	14572	1415	
" 27, "	2	14709	1426	very small charge.

Mean 1419°

Melting temperature 1419°.

Ab_2An_1.—To effect the complete crystallization of this substance, it is best to reduce it to a fine powder and heat very slowly, holding the temperature for many days at 100–200° below the melting point. When thoroughly crystallized, it has a melting temperature which is determinable with reasonable certainty, but neither this nor any of its thermal phenomena approach the more calcic feldspars in sharpness. For this reason a considerably greater variation will be noticed in the melting points tabulated below.

AB_2AN_1.

First Preparation.

Date.	Element.	E. M. F. in MV.	Temperature.	Remarks.
Dec. 10, 1903	A	13726	1362°	
" 15, "	A	13887	1374	
" 16, "	A	13969	1381	very rapid heating.
" 16, "	A	13728	1362	poor.
Jan. 18, 1904	No. 3	13967	1376	covered.
Feb. 29, "	3	13812	1363	"
" 29, "	3	13854	1366	"
			Mean 1369°	

Second Preparation.

Feb. 5, 1904	No. 2	13990	1369°	covered.

Third Preparation.

Mch. 25, 1904	3	13752	1358	
" 29, "	2	13995	1370	
Apr. 5, "	3	13756	1358	
			Mean 1362°	

Melting temperature 1367°.

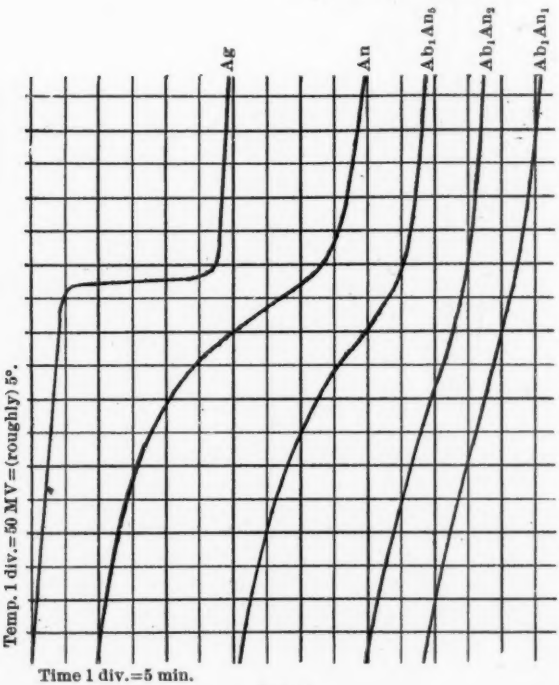


FIG. 7.

From here on to the albite end of the series, viscosity becomes very troublesome in restraining crystallization. The breaks which mark the melting temperature on the heating curve of Ab_3An_1 are so slight as to make the determination difficult and somewhat uncertain. It is not that temperature measurement is less accurate here than elsewhere, for these temperatures are more accessible than the melting point of anorthite, to which reference has been made in this connection. These ultra-viscous materials do not melt at a constant temperature but over a considerable range of temperature, as we shall undertake to show in some detail, with illustrations from photographs, in the discussion of albite. A glance at a series of curves (fig. 7) plotted from our observations upon metallic silver and the feldspars An, Ab_1An_5, Ab_1An_2 and Ab_1An_1 in such a way as to bring their melting points together, will show clearly the nature of this difficulty. The melting point of the metal is sharp, but with anorthite a change in the character of the phenomenon is noticeable. Its poor conductivity for heat and its viscosity, which, though small compared with the other feldspars, is very great compared with silver, have rounded off the corners until a really constant temperature for a period of a minute or more during the melting is nowhere to be found. The nearest approach to a melting *point* is where the rise in temperature is slowest, and this will occur when the portion nearest to the thermoelement (see fig. 1) melts. A series of melting point curves containing a typical one for each of the observed feldspars, is reproduced here exactly as observed (see page 114). The numbers represent the electromotive force of the thermoelements at intervals of one minute, together with a column of differences at the right of each record. The E.M.F. will be seen to approach a minimum as melting progresses and to increase again when it is complete. This minimum rise in the temperature of course indicates the maximum absorption of heat. For purposes of rough orientation 10 MV may be considered equivalent to one degree.

There is no circulation in these viscous melts and nothing to assist in distributing the heat uniformly. The melting point is therefore not marked by a constant temperature but by the point of greatest inclination of the tangent to the curve, with a limit of error which increases with increasing viscosity. With Ab_3An_1 it was barely discernible and with Ab_4An_1 all trace of the heat of fusion was lost.* Slow heating or rapid

* Only a small portion of the charge could be crystallized. The relatively small heat of fusion of the crystallized portion was therefore superposed upon the larger specific heat of the glass. This, together with the effect of the viscosity, destroyed all record of the melting.

TIME CURVES

(in Microvolts as observed).

An		Ab_1An_5		Ab_1An_2		Ab_1An_1		Ab_2An_1		Ab_3An_1	
MV	ΔV	MV	ΔV	MV	ΔV	MV	ΔV	MV	ΔV	MV	ΔV
15050		13530		11700		13400		12480		12754	
	156		300		510		89		53		39
15206		13830		12210		13489		12533		12793	
	135		300		445		84		57		41
15341		14130		12655		13573		12590		12834	
	100		240		305		74		58		43
15441		14370		12960		13647		12648		12877	
	85		190		276		68		53		39
15526		14560		13236		13715		12701		12916	
	68		153		205		63		51		38
15594		14713		13441		13778		12752		12954	
	56		125		154		58		45		35
15650		14838		13595		13836		12797		12989	
	47		104		127		55		43		33
15697		14942		13722		13891		12840		13022	
	41		86		110		51		41		33
15738		15028		13832		13942		12881		13053	
	35		73		100		49		36		31
15773		15101		13932		13991		12917		13082	
	29		63		90		47		35		29
15802		15164		14022		14038		12952		13109	
	27		54		85		45		35		27
15829		15218		14107		14083		12987		13134	
	24		46		79		42		33		25
15853		15264		14186		14125		13020		13160	
	22		39		70		41		33		26
15875		15303		14256		14166		13053		13184	
	16		36		67		40		35		24
15891		15339		14323		14206		13088		13207	
	15		32		70		39		33		23
15906		15371		14393		14245		13121		13229	
	14		27		63		39		33		22
15920		15398		14456		14284		13154		13250	
	13		25		58		39		30		21
15933		15423		14514		14323		13184		13270	
	12		24		57		40		31		20
15945		15447		14571		14363		13215		13288	
	11		21		49		39		33		18
15956		15468		14620		14402		13248		13306	
	9		20		50		42		35		18
15965		15488		14670		14444		13283		13321	
	9		16		44		44		35		15
15974		15504		14714		14488		13318		13337	
	9		17		45		50		37		16
15983		15521		14759		14538		13355		13354	
	9		16		38		67		33		17
15992		15537		14797		14605		13388		13373	
	6		15		42		71		33		19
15998		15552		14839		14676		13421		13393	
	6		15		38				30		20
16004		15567		14877				13451		13415	
	8		14		35				32		22
16012		15581		14912				13483		13439	
	8		13		35				33		24
16020		15594		14947				13516		13466	
	8		14		35				31		27
16028		15608		14982				13547		13493	
	5		14		31				29		27
16033		15622		15013				13576		13520	
	7		15		33				26		27
16040		15637		15046				13602		13548	
	8		17		36				25		28
16048		15654		15082				13627		13576	
	8		18		36				21		
16056		15672		15118				13648			
	8		23		42				18		
16064		15695		15160				13664			
	7		38		51				11		
16071		15733		15211				13675			
	7		63		95				21		
16078		15796		15306				13696			
	9				113				28		
16087				15419				13724			
	12								34		
16099								13758			
	11								36		
16110								13794			
	12								39		
16122								13833			
	12								40		
16134								13873			
	15								41		
16149								13914			
	14								40		
16163								13954			
	18								44		
16181								13998			
	16								52		
16197								14050			
	16										
16213											
	19										
16232											

heating merely acts to change the general inclination of the curve but not to emphasize the absorption of heat.

By way of conveying a concrete impression, it may be added that Ab_3An_1 just above its melting temperature resists the introduction of a stout platinum wire (1·5^{mm} diameter) unless the cold wire is thrust in very quickly and vigorously. If the wire is first allowed to become hot in the furnace, it will give way itself instead. No acceleration of the melting process tending to sharpen the break in the curve appears to be possible without the introduction of new substances or new conditions (water vapor under pressure for example) which would take the experiment outside the definition of a "dry melt." We have undertaken some preliminary experiments in these directions, but they belong to another phase of the subject.

A number of efforts were made to locate the melting temperature of Ab_3An_1, which are given in the list below. Although two days were required to crystallize each charge of the material sufficiently for a determination, the recorded numbers possess but little significance, as will be clear from the foregoing.

AB_3AN_1

First Preparation.

Date.	Element.	Electromotive Force in MV.	Temperature.	Remarks.
Nov. 23, 1903	A	-----	1325°	
" 25, "	A	13415	1336	
" 28, "	A	13698	1359	
Dec. 26, "	A	13319	1328	
Jan. 14, 1904	No. 3	13893	1370	
		Mean	1344°	

Second Preparation.

Mch. 11, 1904	A	13218	1320	
" 14, "	No. 3	13469	1335	
			1329°	

Approximate melting temperature 1340°.

Ab_4An_1.—With Ab_4An_1 a third proof of the identity of composition of the first crystals to separate and the vitreous residue was obtained. The optical identification of this feldspar is absolute. If we could obtain crystals at all in a melt of this chemical composition, therefore, it would offer a crucial test of the relation of the solid and liquid phases in a part of the curve where no melting point or specific gravity determination upon crystals was possible. After some days of nearly continuous heating at a temperature somewhat below its assumed melting point, a few crystals of Ab_4An_1 were obtained and identified.

Albite.—From the experiments upon natural albite and orthoclase, which have been described, and after observing the effect of the increasing viscosity as we approached the albite end of the artificial plagioclase series, we had no expectation of finding a melting point for either in the ordinary sense. Nor did we in fact succeed in locating a point of any real significance in this connection. The various trials which were made were simply calculated to throw all the light possible upon the character of the change from (crystalline) solid to liquid in such extremely viscous substances. The return change or recrystallization of such substances from the melt (solidifying point) without the introduction of modifying conditions has never been accomplished. The time required to do it is certainly very great, probably much greater than the demonstration is worth at the present stage of experimentation in this field.

Crystalline albite has been produced under exceptional conditions several times—by Hautefeuille,* by heating a very alkaline alumino-silicate with sodium tungstate for 30 days at 900°-1000°; by Friedel and Sarasin,† using an atmosphere of water-vapor under high pressure and a moderately high temperature (an aqueo-igneous fusion); by J. Lenarčič,‡ at ordinary pressure and high temperature by crystallization out of a mixture of melted albite and magnetite (1 part magnetite, 2 parts albite by weight), and by others. It may be noted in passing that, entirely apart from the solution relations, the last mentioned process reduces the viscosity to an entirely different order of magnitude from that of pure albite; magnetite melts to form a thin liquid almost of the consistency of water and even in 1:10 solution with albite forms a fairly mobile liquid. We endeavored to repeat portions of the work of Hautefeuille and Lenarčič, but were obliged to postpone a systematic inquiry into the conditions of crystallization which involved the addition of other components or extraordinary pressures, until our plant could be somewhat extended.

Hautefeuille describes his successful preparation as a "solution" of the alkaline alumino-silicate in sodium tungstate out of which the albite slowly crystallizes after long heating, but he remarks that the crystallization does not take place if the mixture is heated sufficiently to melt the components of the charge into a homogeneous glass. In that case he obtained only a vitreous white enamel. The case does not appear, therefore, to be one of simple solution, out of which the same

* Hautefeuille, Annales de l'École Normale Supérieure, 2d series, ix, p. 363, 1880.

† Friedel and Sarasin, Bull. Min., clviii, 1879; lxxi, 1881.

‡ J. Lenarčič, Centralblatt f. Min., xxiii, 705, 1903.

solid phase always reappears upon reproducing given conditions of temperature and concentration. On the contrary, as Hautefeuille describes the experiment, the components of the albite remain as independent solid phases, which are then assembled in some manner through the intermediary action of the melted tungstate.

Notwithstanding the fact that our interest was confined for the moment to the mere production of a small quantity of chemically pure crystalline albite, we ventured to proceed along the lines of Hautefeuille's unsuccessful trial. We first prepared a chemically pure albite glass, i. e., we melted the components into a homogeneous mass before adding tungstate. This glass was then finely powdered, thoroughly mixed with an excess of powdered sodium tungstate and maintained continuously for 8 days at 1100°. Upon removing from the furnace at the close of the heating, both albite and tungstate were found to have been completely melted and to have separated into two distinct layers according to their specific gravities, the albite glass being above, and showing no trace of crystallization. A second charge was then prepared with only 50 per cent of the tungstate, powdered and mechanically mixed as before, and maintained at a temperature of 900° for 17 days. This time we were successful. After the sodium tungstate had been dissolved away with water, the albite appeared as a powder of about the fineness to which it had originally been pulverized, except that the fragments were now crystalline and apparently homogeneous albite. In thin section, under the microscope, to our considerable surprise, it appeared that the original glass fragments were unchanged in form. The bounding surfaces were all conchoidal fractures, as they came from the hammer, and evidently had not been in solution with the tungstate at all. Its optical properties showed it to be undoubted albite and the specific gravity was 2·620.

The preparation of albite which we had synthesized by heating with an equal weight of sodium tungstate was first purified by thorough washing with warm water, but this was not sufficient to remove all the tungstate. A determination of tungstic acid showed 0·62 per cent still present, which is equivalent to 0·78 per cent of sodium tungstate. After removing the water by heating carefully to a dull redness, the product was submitted to a microscopic examination, which showed it to be entirely crystalline and apparently homogeneous. Determinations of the specific gravity gave 2·620 (see table, p. 128). If this is corrected for 0·78 per cent of sodium tungstate of specific gravity 4·2, we obtain 2·607.

A portion of this preparation was then purified further by fusing for a few minutes with acid sodium sulphate (Haute-

feuille) at as low a temperature as practicable, after which the excess of sulphate was extracted with water and the product dried (the temperature was raised to a dull red heat to remove all water) and analyzed.

	Found.	Calculated.
SiO_2	68·74	68·68
Al_2O_3 and Fe_2O_3	19·56	19·49
Na_2O	11·73	11·83
SO_3	·02	
WO_3	·16	
	100·21	

The specific gravity of it was 2·604, which may be corrected as before for the remaining trace of tungstic acid assumed to be in the form of the sodium salt. The value then falls to 2·601.

A second portion of the same albite was purified by another process. Instead of fusing with acid sodium sulphate, the powdered sample was first digested for a short time with dilute hydrochloric acid (1:1), which set free tungstic acid. The excess of hydrochloric acid was removed with water, the tungstic acid with ammonia, and finally the excess of reagent and the ammonium tungstate by further washing with water. When dried at a low red heat, the preparation had the following composition:

	Found.		Calculated.
SiO_2	68·91		68·68
Al_2O_3	18·95	19·13	19·49
Fe_2O_3	·18		
Na_2O	11·59		11·83
WO_3	·22		
H_2O	·13		
	99·98		

The specific gravity determination gave 2·615, which when corrected for a small amount of sodium tungstate becomes 2·612. If, as is possible after the above treatment, the tungstic acid is present as the anhydride, sp. gr. 7·1, the correction would lower the value to 2·605, in excellent agreement with the other determinations.

The products of both methods of purification were carefully scrutinized by the microscope, but no conclusion could be reached as to which was the purer. Neither the sodium sul-

phate fusion nor the digestion with acid and ammonia appeared to have changed the particles in the slightest degree. Diligent search was made for opaque or amorphous matter on the surface of the grains, or any other indication of decomposition, but none was found. While the chemical analysis indicates a rather higher purity for the first product, purified by fusion, the differences are nearly within the limits of error and therefore hardly conclusive. Both powders were ground finer than usual for the specific gravity determinations to avoid errors introduced by a spongy structure.

Reverting now to Hautefeuille's directions, it is clear that glass of albite composition crystallizes homogeneously under substantially the conditions which he obtained, as well or better than the mechanically mixed component parts; but the part played by the tungstate requires some further experimental study before a conclusion can be reached.

Except for the specific gravity, the experiments upon crystalline albite and orthoclase which follow were made upon natural specimens from well-known localities (a fragment of the Mitchell Co. albite is shown in Plate I, 1), for which we are indebted to Dr. G. P. Merrill of the National Museum and Dr. Joseph Hyde Pratt, State Mineralogist of North Carolina. The specimens were selected with great care, but like all natural specimens, they contained other feldspars and inclusions. The analyses follow:

	Albite. (Amelia Co., Va.-Nat. Mus.) Found.	Calculated, Anhydrous.	Albite. (Mitchell Co., N. C.-Pratt.) Found.	Calculated, Anhydrous.	Microcline. (Mitchell Co., N. C.-Nat. Mus.) Found.	Calculated, Anhydrous.
SiO_2 ..	68·22	68·71	66·03	66·42	65·49	65·83
Al_2O_3 .	19·06	19·20	20·91	21·03	17·98	18·07
Fe_2O_3	·15	·15	·18	·18	·36	·36
CaO ..	·40	·40	2·00	2·00	·42	·42
Na_2O .	11·47	11·53	9·97	10·03	2·29	2·30
K_2O ..	·20	·20	·70	·70	12·95	13·02
H_2O ..	·69	....	·59	....	·51	....
	100·19		100·38		100·00	

It will be remembered that in the preliminary experiments (p. 98) the heating curve of these natural feldspars did not show an absorption of heat which we were able to detect; our first step was therefore to find out what manner of process it was by which a charge of crystalline albite or orthoclase became amorphous without leaving a thermal record behind.

We prepared a charge of albite glass from a previous melt powdered to "100-mesh." In this glass powder a small crystal fragment (perhaps $2 \times 5 \times 10^{mm}$), from the same original speci-

men and therefore of the same chemical composition, was imbedded beside the thermoelement as indicated in fig. 8. This charge was heated slowly to exactly 1200°, slowly cooled again and several thin sections prepared from the crystal fragment and its immediate neighborhood. What the microscope showed can best be seen from the accompanying illustrations (Plate I, 2 et seq.),—groups of crystal fragments of microscopic size, preserving their original orientation (extinction) perfectly but with narrow lanes of glass where cleavage and other cracks had been, forming a perfect network without a trace of disarrangement. Considerable melting had taken place but no flow. Neither had the charge as a whole made any movement to take the form of the containing vessel after sintering together (fig. 9).

Surmising that we had accidentally hit upon the approximate melting temperature, a fresh charge of like material was

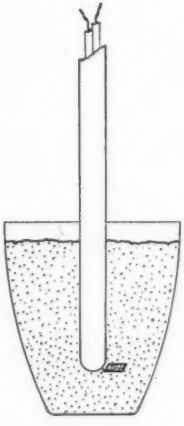


FIG. 8.

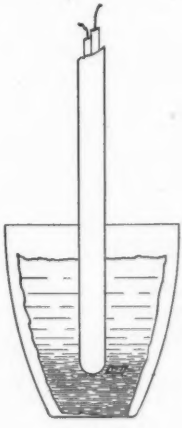


FIG. 9.

prepared, and the same experiment carefully repeated except that the temperature was carried up to 1206° and maintained there for 30 minutes. Instead of showing the melting to be complete, the slides (Plate I, 3) looked precisely like the first save that the lanes of glass were somewhat wider and the crystal fragments relatively smaller than before. Further trials under precisely the same conditions with the temperature increased to 1225° (Plate I, 4) and 1250° (Plate I, 5) respectively, for like periods of time, showed only more advanced stages in the same process. In the latter case the

remaining crystal fragments were relatively very small compared with the separating lanes of glass, but the orientation of the tiny particles still remained perfectly undisturbed.

The evidence contained in this series of slides shows plainly that we have here an unfamiliar condition—a case of a crystalline compound persisting for a long time above its melting temperature for a given pressure. Albite or orthoclase glass sinters tightly at 800°. At the temperature when melting began, therefore (below 1200°), the charge consisted of crystal fragments of microscopic size imbedded in a large vitreous mass of the same composition and known temperature. These fragments melted so slowly over the 50° included between the first slide (Plate I, 2) and the last (Plate I, 5), with the rate of heating slow (1° in 2 min.), and the upper temperature continued for 30 minutes, as to leave considerable portions unmelted at the close. Furthermore the extreme viscosity, of which further evidence will be given directly, and the absence of any disturbance in the orientation of the particles indicating flow, assured us that the lanes of glass represented actual melting and not an inflow of glass from without. Finally, the perfectly homogeneous character of the glass and the unchanged appearance of the crystals as heating progressed, gave no hint of any chemical decomposition.

In the hope of obtaining a point of value for comparison with the melting points of the other feldspars, some time and patience were expended in trying to locate the lowest temperature at which certain evidence of melting appeared. We did not extend any single trial beyond a single day, so that our results can not pretend to establish the lowest point at which albite melts. Such an effort with a natural specimen known to contain impurities would yield nothing of value. Mitchell County albite showed signs of melting after four hours at 1100°. Under a high power the crystal edges appeared weathered or toothed—strongly resembling the incipient melting of the ice on a frosted window pane. These extremely fine teeth could be followed through the slide on exposed edges. At 1125° (Plate I, 6, ×300) a four-hours heating gave unmistakable glass in tiny pockets and lanes.

The above experiments with the Cloudland albite were completed before we obtained the Amelia County material, but the latter proved to be so much nearer to the type of pure soda feldspar that nearly all the experiments were repeated with it except that the crystal blocks were imbedded in powdered crystals. We did not develop any new fact, however; the effects noted above reappeared in the same order except perhaps that melting went on a little faster in the Amelia County specimen. As much melting was found after one-half hour at

1200° with the Amelia County sample as the Cloudland (Mitchell County) showed in the same time at 1225°, which is readily enough explained by the relatively large quantity of lime (anorthite) in the latter.

Since both time and temperature enter into the delimitation of the metastable region, further trials at temperatures above 1250° did not seem likely to add anything to the knowledge already obtained. And if the heating were very rapid, the temperature differences within the charge would be considerable. A few isolated crystalline fragments were found in an orthoclase melt which had been heated as high as 1400° for another purpose. Another which had reached nearly 1500° showed no orthoclase, but one or two minute quartz inclusions still remained undissolved.

We made a rough attempt to get a more tangible idea of the viscosity of these feldspars at their melting temperature in the following way. A long, slender sliver (perhaps 30x2x1^{mm}) of albite and one of microcline were chipped from larger portions, spanned across small empty platinum crucibles, and placed side by side in the furnace. These exposed crystals were heated to 1225° for three hours. When removed, they were completely amorphous (melted) but retained their position with hardly a trace of sagging.

After this a number of similar slivers were prepared, mounted in the same way, and heated to temperatures of from 1200° to 1300° for a few moments. At their highest temperature a platinum rod was inserted through a hole in the top of the furnace and allowed to rest as a load upon the middle of the crystal bridges. Under this load the partially melted slivers gradually gave way, and were taken from the furnace in the various forms shown in the illustrations. Slides cut from these showed no squeezing out of the melted portion between the crystal fragments on the side toward the center of curvature, or open cracks on the outer side (Plate I, 7, 8.) On the other hand, a variable extinction angle in an unbroken crystal fragment frequently gave unmistakable evidence of the bending of the crystal as well as the vitreous portion. From these qualitative experiments it seems possible to assert with confidence that the order of magnitude of the viscosity of the molten portion (glass) is the same as the rigidity of the crystals at these temperatures.

Plate I, 7, shows a piece of Mitchell Co. albite heated to 1200° under load. The sagging is indicated by the curved cleavage cracks. Plate I, 8, shows a sliver of microcline which has been heated to 1200° under load. The sagging is shown by the curvature of the crystal edges and the cleavage cracks.

The black portions are glass. It is interesting to observe that while the crystal has melted completely across, there has been no displacement of the cleavage plane.

The preceding experiments gave a clear idea of the phenomena attending the melting of albite and orthoclase, and convinced us that the absorption of heat accompanying fusion, which we had searched for in vain upon the heating curves in the earlier experiments, had eluded us merely because it was extended over so long a stretch of the curve as not to be noticeable. Some very exact measurements of the temperature change from minute to minute were therefore made in the hope that a more intelligent search might be more successful. Separate charges of glass and of crystals of the same composition and of equal weight were prepared and successively heated in the same furnace with the same current. The specific heat is of course not identical in the two cases, but the curves were comparable in form. Above 1100° we felt sure that one of the curves must contain an absorption of heat which would be absent from the other. Such

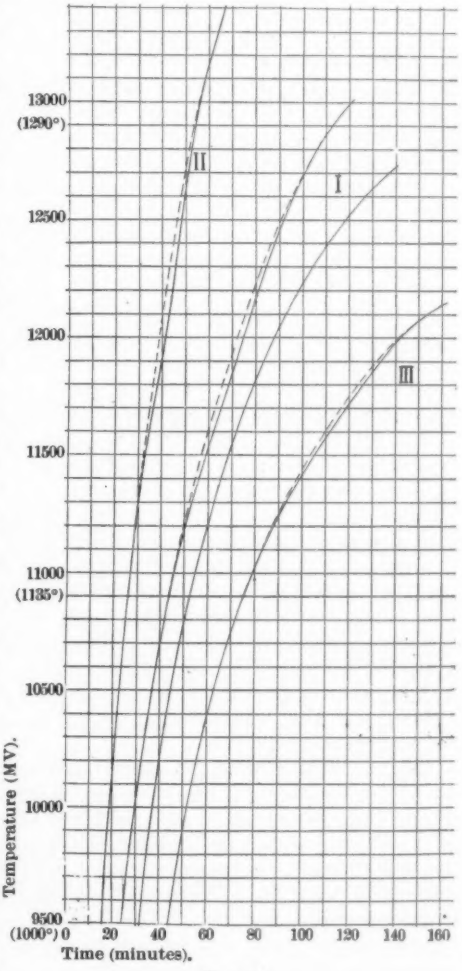


FIG. 10.

a pair of curves, I, taken from the microcline measurements, is reproduced in the adjoining figure (fig. 10), and appears to show such an absorption clearly, extending from 1135° to 1275°. The dotted line shows the course of the curve without the absorption, as inferred from the glass curve. The same figure contains two other curves (II, III), similarly treated, which were made upon fresh charges of the same material, but with different rates of heating. It will be noticed that the absorption begins to be noticeable at a slightly lower temperature if the heating is slower.

This peculiar behavior shown by compounds which melt to form hyperviscous liquids seems not to have been observed before and to contain features of more than ordinary interest. Here are evidently crystalline substances which not only can exist for considerable periods of time at temperatures far above their melting temperatures, but which melt with extreme slowness in the lower portion of this range of instability. It would certainly be no exaggeration to say that the albite with which we worked would require some weeks to reach the amorphous state if maintained at a constant temperature of 1125°.

An interesting question arises here as to the state of the crystalline material at temperatures above its melting point. It is easily conceivable that the crystals are merely superheated without loss of any of their properties as solids, and that they thus present an analogy to superheated liquids. In the transformation (Umwandlung) of a solid crystalline substance into another crystal form, such superheating has long been known. The change is dependent upon temperature and pressure like ordinary fusion, but it is possible to pass the transformation temperature in either direction. This must be due to the unfavorable opportunity for molecular motion which solids afford, and the latter should differ in no essential particular from ultraviscosity.

On the other hand, it does not seem a violation of any known principle to conceive cases of unstable equilibrium in which the molecules of a liquid are oriented as in a crystal. Maxwell's demons might arrange them much like a school of fish and there is no apparent reason why the fluidity should be destroyed thereby. Were such an arrangement one of minimum potential, the mass would be a liquid crystal. In the supposed case such a substance would possess a melting point dependent upon the temperature and pressure, above which Maxwell's definition* of a true solid—that its viscosity be infinite—would no longer obtain, although deorientation might not become apparent, in the face of extreme viscosity, for a

* Maxwell's Scientific Papers, vol. ii, p. 620.

considerable time afterward. Such a melting point would be determinable only with the greatest difficulty, for all the functions—mechanical, thermal or electrical—which usually become suddenly discontinuous at the melting point would be equally powerless to define a change of state in the face of such extreme molecular inertia.

In substances like these, which are still viscous at the temperature of the electric arc, the sharpness of a minimum due to heat absorption, for example, is not dependent upon the magnitude of that absorption entirely, but also upon the rapidity with which the change which involves it proceeds. In albite and orthoclase, the velocity of this change is very small.

Specific Gravity.—The study of the specific gravities yielded one interesting result which was not anticipated. The artificial feldspars, being chemically pure and homogeneous, gave a perfectly definite specific gravity which could be determined with great accuracy if the specimen was completely crystallized. If vitreous inclusions were still present, the results were of course variable and were all too low. It was anticipated that the density of pure glasses, transparent and free from bubbles, as they were in the more calcic members of the series, might yield values varying more or less with the rate of cooling, or after annealing, but this did not prove to be the case. Our results did not vary more than two units in the third decimal place in the same preparation even with the more calcic feldspars which required to be very rapidly chilled in order to cool the melt without crystallization.

The determination of specific gravities is a trite subject, but we have found the common methods liable to such grave errors that we venture to give some useful details. The error due to the evaporation of water about the stopper of the pycnometer is very much less with finely ground stoppers than with coarse grinding, and if the stopper is slightly vaselined just before the final weighing, the error from this cause will hardly affect the third decimal place with 25^{cc} pycnometers. The simplest form of flask with a small capillary opening in the stopper, is, in our judgment, far superior to one carrying a thermometer. The temperature should be made sure by the use of the thermostat.

For removing the air from a powdered charge, we used the device of G. E. Moore,* slightly modified, as indicated in the accompanying sketch. The bulb *A* contains boiled water.

*G. E. Moore, Jour. prakt. Chem., ii, p. 319, 1870.

When the apparatus is exhausted, the water is allowed to flow back into the pycnometer containing the charge; then by tapping and warming with water at 40–50° to produce boiling within, the air is effectively removed. The material projected from the flask, if the boiling is violent, is then washed back from the tube *B* with boiled water and any small particles remaining are washed into a tared dish and finally weighed. It is very important that not the smallest grain of material should get into the ground joint between the neck and stopper of the pycnometer. To obviate this, wipe out the neck with filter paper before stoppering and burn it in the tared dish.

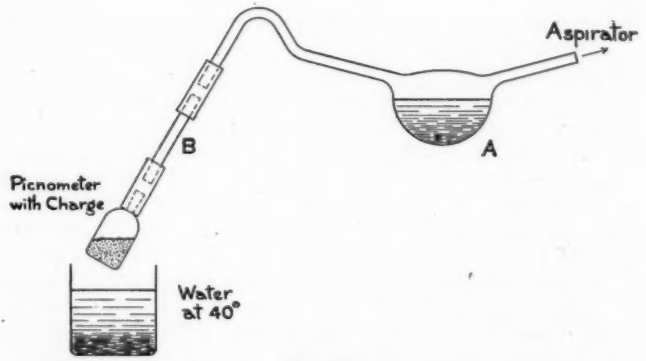


FIG. 11.

If the powder is very fine it is advisable to allow the filled pycnometer to stand for some hours in the thermostat, in order that suspended material may settle. With a 25^{cc} pycnometer and 5 to 10 grams of material, this method usually yields concordant results to the third decimal place, and the error from all causes should never be greater than two units ($\pm$ 1) in the third place. A determination of this accuracy is of course subject to a correction for buoyancy, and all the numbers which follow have been thus corrected.

There is another error to which accurate specific gravity determinations upon powdered minerals will be subject unless suitable precaution is taken. The exposure to the air during the period of grinding the samples gives opportunity for the condensation of sufficient atmospheric moisture upon the grains to affect the weight in air. The amount varies measurably with the size of the grains, as will be seen from the accompanying data, and probably with the degree of saturation of the atmosphere and the time of exposure.

DETERMINATION OF MOISTURE IN 1 GR. OF POWDERED MINERAL UPON EXPOSURE TO THE AIR.

Mineral.	Fineness (mesh).	Moisture.
Orthoclase (natural glass)	<150	·0061 gr.
Ab_1An_3 (artificial glass)	selected, coarse	·0000
" (" cryst.)	<100 >120	·0010
Ab_1An_1 (" glass)	<100 >120	·0007
" (" cryst.)	<100 >120	·0010
Ab (natural ")	coarse	·0006
Ab (" ")	<150	·0069
Orthoclase (natural cryst.)	<120 >150	·0011 gr.
" (same sample)	<150	·0031
" (" ")	still finer	·0059
Orthoclase (artificial glass)	everything <100	·0065 gr.
" (portion of same)	>150	·0022

<= finer than > = coarser than

In the last two groups, note that the moisture in selected portions of the same sample varies with the fineness.

We also verified the conclusion of Bunsen* that this adsorbed moisture is not removed at temperatures only slightly above 100° but requires 600° to 800°—equivalent to a low red heat. Several samples for which the moisture had been determined were laid away in corked test tubes for a number of weeks, after which redetermination gave exactly the former value.

It is worth noting in this connection that these measured quantities of adsorbed water are of the same order of magnitude as those usually obtained for the water content in feldspar analyses,† where again, of course, the finer the sample is ground for the analysis, the greater the possible error from this cause. It may be that a part and occasionally all of the moisture usually found in these analyses is adsorbed and the significance of its presence there mistaken.

The number of feldspars of which specific gravity determinations could be made was limited only by the possibility of obtaining complete crystallization within a reasonable time. Thus Ab_2An_1 was reheated many times before a constant value was reached. Ab_3An_1 required 17 days and Ab_4An_1 was not completely crystallized in any of our attempts. Crystalline albite was produced under other conditions.

The specific gravities of the glasses and of so many of the crystalline mixtures as we could obtain are tabulated below:

* Wied. Ann., xxiv, p. 327, 1885.

† Dana, System of Mineralogy, 6th ed., p. 314 et seq.

SPECIFIC GRAVITIES OF ARTIFICIAL CRYSTALLINE FELDSPARS.

An	Ab_1An_5	Ab_1An_2	Ab_1An_1	Ab_2An_1	Ab_3An_1	Ab (First Determination)	Ab (Corrected)
2·764	2·734	2·710	2·680	2·660	2·650	*c* 2·620	2·607
2·765	2·734	2·708	2·680	2·660	2·648	2·620	
				2·660			
a 2·767	*a* 2·732	*b* 2·710	*b* 2·679	*b* 2·659		*d* 2·614	2·601
	2·732	2·710	2·677	2·660		2·615	
							f 2·612
	a 2·734					*e* 2·604	*g* 2·605
Mean 2·765	2·733	2·710	2·679	2·660	2·649		2·605

SPECIFIC GRAVITIES OF FELDSPAR GLASSES.

2·700	2·647	2·593	2·533	2·482	2·458	2·383
2·700	2·649	2·594	2·534	2·482	2·459	2·382
	2·648	2·591		*a* 2·485		
	2·647	2·591				
	2·648	2·590				
	2·649	2·588				
	2·647					
	2·647					
Mean 2·700	2·648	2·591	2·533	2·483	2·458	2·382

Determinations in duplicate are enclosed in brackets.

a. Another preparation.

b. Same material reheated for several days at temperatures about 150° below the melting point.

c. Contained about 0·8 per cent of sodium tungstate.

d. Purified by warming with dilute hydrochloric acid, then with water, and afterwards with ammonia.

e. Purified by fusion with acid sodium sulphate.

f. Assuming the residual tungsten to be present as Na_2WO_4.

g. Assuming the residual tungsten to be present as WO_3.

Sintering.—Incidental to this work upon the relation between the feldspars, we made a great many observations upon the sintering of powdered minerals, both crystalline and vitreous, of natural and artificial composition. While the results have not enabled us to offer positive conclusions of importance, they are worth a note in passing,

Powdered glasses sinter slowly or rapidly several hundred degrees below the melting temperature of crystals of the same composition. When the viscosity is relatively slight (anorthite) crystallization begins at a low temperature and proceeds very rapidly, the sintering probably being due to the interweaving of the crystal fibers during their formation. In viscous glasses (albite) sintering also begins at low temperatures,—

the finer the powder and the slower the heating, the earlier the first traces appear. Long continued heating, even at very low temperatures (700°), yields a perfectly continuous cake (except for the included bubbles) the surface area of which constantly tends toward a minimum. There is no doubt that the sintering of powdered glasses is due to flow in the undercooled liquid and is a phenomenon in liquid viscosity. All the feldspar glasses sintered readily between 700° and 900°, depending on the fineness of the powder and the time.

Powdered crystalline feldspars do not sinter readily below their melting temperature. Indeed we were at first inclined to the view that when only pure, dry, stable crystals are present, they do not sinter however finely they be powdered. We observed the phenomenon in natural albite at 1000° but the crystals were not wholly free from inclusions which may have caused chemical reactions resulting in cementation. Crystalline fluorite also sinters 300° below its melting point, but here we were able to establish a decomposition. Acid fumes were evolved during the experiment and the sintered cake contained 1 per cent of free lime. Our final experiments with long continued heating for specific gravity determinations, however, showed that the purest feldspars we could prepare, even after they had reached their maximum density, still sinter very slowly. Thus Ab_1An_1 powder, which was shown by a determination of its specific gravity to be holocrystalline, formed a compact chalky mass in four hours at a temperature about 150° below its melting point; in three days it was as hard as porcelain. Other feldspars showed the same behavior. It is hardly possible that inhomogeneities sufficient to produce diffusion between portions of different concentration, could have existed in these charges. There is considerable indication that some of the crystalline nuclei grow at the expense of others—perhaps through exceedingly slow sublimation—which may account for it.

We made repeated attempts to locate some fixed sintering point which should be characteristic of a particular material by means of continuous measurements of the electrical conductivity, but they all indicated that no such point existed. The conductivity of a dry powder increases enormously after sintering begins and would therefore seem to offer a most sensitive test, but the phenomenon is altogether gradual even with a crystalline feldspar containing only a small percentage of glass. We purpose to extend these observations to other substances

Conclusions.—It now remains for us to gather the results together and to draw such conclusions as they appear to justify.

(1) If the melting points are now plotted in a system of

which they form the ordinates, while the percentage compositions of the different feldspars form the abscissas (fig. 12), we discover, within the limits of accuracy of possible measurement at these temperatures, a nearly linear relation: the melting point varies very closely with the composition. We have no maximum, no minimum, no branching of the curve, but from each fusion there separates a solid phase of the same composition as the vitreous matrix. In Ab_1An_6 it will be remembered that this was proved by the separation and analysis of the two phases; in Ab_1An_2 partial crystallization was accomplished in the first cooling and the remainder in a subse-

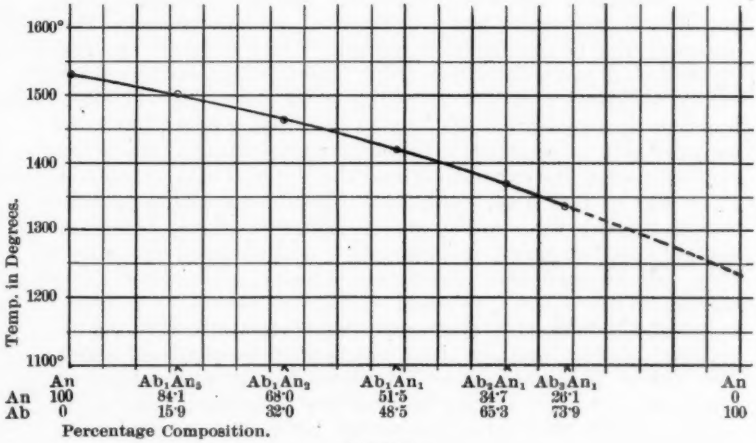


FIG. 12.

quent reheating and cooling, the two groups of crystals proving optically identical; a small quantity of Ab_4An_1, which admits of absolute identification optically, was crystallized out of a melt of that composition and readily recognized. Moreover, evidence to show that the same phase always separated was likewise presented.

Stated in this way, the relation appears to be a simple additive one in which liquid and solid phases of like composition are stable in all proportions of the components and behave like a series of separate feldspars. But as soon as we consider it with reference to the laws of solution and the phase rule, it can not be explained in this simple way.

First of all, the phase rule tells us at once that we can have no true compound here between the components albite and anorthite, for such a compound would mean one more component and an additional phase in every solution before equilibrium could be established. Moreover, if the mixture had

been eutectic in character, the component (albite or anorthite) which happened to be in excess would have crystallized out in each case, causing a continual change in the composition of the remaining glass until the eutectic proportion was reached and the resulting charge would have contained only crystals of one (or, in case of hysteresis, both) of the components and the eutectic. Our curve is continuous and the resulting charges homogeneous for all proportions of the components. Lane's suggestion* that the triclinic feldspars from a eutectic series in which the eutectic proportion is at or near Ab_2An_3 is therefore not borne out by our experiments.

Laying aside the eutectic mixture, and passing over to solutions of components which are miscible in many or all proportions, we find a small number of examples, chiefly organic compounds, which have been studied as types by Roozeboom, Küster, Bodländer, Garelli, Bruni, Van Eyk and others, among which our series appears to fall.

Laws of Solutions.—From the physico-chemical standpoint, the case we now have in hand closely resembles Küster's problem of 1891.† His measurements were made upon mixtures of organic compounds of low melting point, while ours reached a maximum temperature of 1532°, but we have, between albite and anorthite, an exactly similar series of solid solutions the melting points‡ of which change in nearly linear relation to the percentage of the two compounds which enter into their composition.

This simple linear relation was called by Küster perfect isomorphism, and he formulated the "Rule" which has since borne his name, that the solidifying point of an isomorphous mixture lies on a straight line joining the melting points of the components and can be calculated from the percentage composition of the mixture. If this line proved to be slightly concave or convex, as it did in most cases, imperfect isomorphism was assigned as the cause. To this rule an objection was raised by Garelli§ and elaborated by Bodländer‖—if the solid solution behaves like other solutions, a small quantity of component B added to component A can only lower the solidifying point of A when the solid phase is richer in A than the liquid phase. The reasoning is this (Bodländer): let x_1 (fig. 13) be the vapor tension curve of component A in the liquid state, y_1 the solidifying point (t_1) of A, and z_1 the vapor tension

* Lane, Journal of Geology, XII, ii, p. 83, 1904.

† F. W. Küster, Zeitschr. für Phys. Chem., viii, p. 577, 1891.

‡ Küster measured solidifying points, but we have pointed out above that such measurements lead to no positive result in liquids of such viscosity as the feldspars in which equilibrium is not established during solidification. Undercooling rarely appeared at all in Küster's cases.

§ F. Garelli, La Gazzetta Chimica Italiana, xxvi, p. 263, 1894.

‖ Bodländer, Neues Jahrb. f. Min., Beilage, Bd. xii, p. 52, 1899.

curve of solid A. Now if a small quantity of B is added and the solid phase which crystallizes out contains the same proportions of A and B as the liquid mixture in which it formed, the vapor tensions of the liquid and solid phases must have been lowered equally and the solidifying point will fall at y_2 with the same temperature as the pure solvent. (Equality of vapor tension in the solid and liquid phases determines the temperature of change of state.) If A crystallizes alone from $A + B$, the vapor-tension curve will continue on to z_2 and the temperature of solidification fall to t_2; while if the solid phase contains both components but is richer in A than the liquid phase, solidification will occur at an intermediate point.

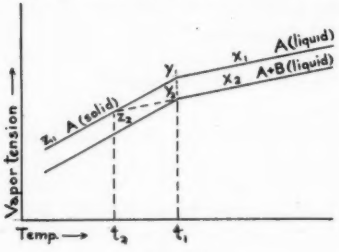


FIG. 13.

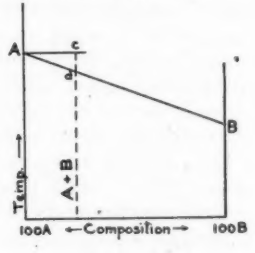


FIG. 14.

Fig. 14 will serve to show the crucial character of the issue raised. The ordinates represent temperatures, and the abscissas percentages of A and B. Küster finds his solid and liquid phases identical in composition within the limits of experimental error and the solidifying temperature on the line AB at a point which can be determined from the proportions of the components—at d for example. But the laws of dilute solutions tell us that if the phases are identical in composition, the solidifying point of $A + B$ must fall at c, i. e. must remain the same as for pure A.

The temperatures at which Küster's observations were made and their painstaking character leave no doubt as to the validity of the experimental fact. Neither can it be objected that Küster's solutions were not sufficiently dilute to reveal the true relation, for the observations upon naphthaline and β-naphthol have been repeated by Bruni* with very dilute solutions of one of the components in the other, and completely verified.

Now the laws of solutions hold for solid solutions even for moderately high concentrations (Bodländer) when the components are not isomorphous, and on the other hand even liquid crystals, when isomorphous, follow Küster's Rule more nearly than the law of solutions.

* G. Bruni, Atti della Reale Accademia dei Lincei, series 5, vii, p. 138, 1898.

An extended discussion of existing data from this standpoint would involve us in unnecessary detail, but there can be no question that Kuster's Rule represents the data which have been gathered upon isomorphous mixtures—at least approximately—while the laws of dilute solutions appear to fail of application there. On the other side, the Rule admits of no independent theoretical derivation. Van't Hoff* suggests that judgment be suspended pending the accumulation of further data and intimates that the close similarity of chemical composition and molecular structure in compounds which form isomorphous mixtures, gives them an unusually close interrelation, and their influence one upon the other may render a simple theoretical treatment very difficult.

Our case is especially interesting when considered from this standpoint, but it distinctly emphasizes the difficulty rather than helping toward its solution: (1) Although the chemical reactions of albite and anorthite are not of such a character as to prove or disprove a close analogy between them, a comparison of their formulas certainly does not suggest an isomorphous relation. If their formula weights represent true molecules, they possess the same number of atoms to the molecule ($NaAlSi_3O_8$, $CaAl_2Si_2O_8$) and the group Si_2O_8 in common, but the remaining atoms taken separately are not mutually replaceable. (2) The melting points of the components in the feldspar series are very far apart—more than 300°—while Küster's organic mixtures were all included within a narrow temperature interval (2° to 56°). For reasons which will appear presently, both Garelli† and Roozeboom have pointed out that the farther apart the melting points of the components, the less probable is the linear relation. (3) The homogeneity of the solid phase is established within 1. per cent by the optical examination of the slides. Moreover separate chemical analyses of the solid and liquid phases of the mixtures Ab_1An_3 in an exceptionally favorable case showed still closer identity of composition.

It appears altogether improbable that the laws of solutions can apply in the face of so extreme a controverting case.

If it has proved difficult to bring the isomorphous mixture within the general laws of solutions, a most satisfactory theoretical derivation of the conditions of equilibrium in such mixtures has been developed by Roozeboom. No other principle is required than the second law of thermodynamics as applied to solutions by Gibbs:—A system of substances will be in equilibrium for a particular pressure when the thermodynamic potential (ζ-function) of the system is a minimum. The scheme of representation is the graphical one proposed by

* Van't Hoff, Vorlesungen üb. Theoret. u. Phys. Chem. (Braunschweig 1901.) Part II, p. 64.

† F. Garelli, loc. cit.

van Ryn van Alkemade* and is itself a powerful instrument of analysis in this field.

Roozeboom distinguishes three general classes of isomorphous mixtures:

(1) The components are miscible in all proportions from 0 to 100 per cent in both solid and liquid phases.

(2) Miscibility is limited to certain concentrations.

(3) More than one type of crystal occurs.

In the feldspars we are concerned with the first class only, but here also Roozeboom distinguishes three possible types:

Type I. Melting (or solidifying) points of the mixtures lie on a continuous curve joining the melting points of the components and containing neither maximum nor minimum.

Type II. The curve contains a maximum.

Type III. The curve contains a minimum.

*Zeitschr. f. Phys. Chem., xi, p. 289, 1893.

Except for the suggestions of Vogt to which reference has been made, this method seems not to have been utilized for the study of mineral solutions before. A brief outline of it will therefore be given here.

In a system of rectilinear coördinates (fig. 15) the ordinates may represent the potential of a particular system—(Gibbs' ζ-function, not directly measureable) and the abscissas the number of gram-molecules of solvent (water for example) supposed to contain 1 gr. mol. of solute. In other words, every point of the curve represents a solution of which the x coördinate is concentration and the y coördinate the potential. The conditions of pressure and temperature are assumed constant for a particular diagram.

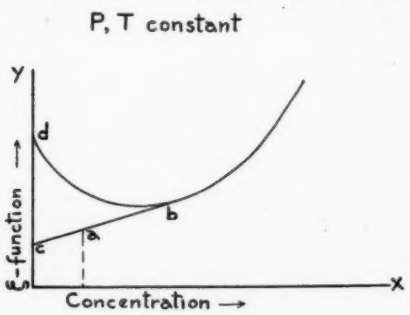


FIG. 15.

Every such curve for substances soluble in all proportions will be convex downward, otherwise there would be some particular point on the curve which would not represent a minimum potential for a particular composition and the solution would tend to separate into two, the mean potential of which would be lower.

The condition for equilibrium between such a solution and its solid phase (pure salt) may now be readily found. Lay off on the ζ-axis a distance equal to the potential of the solid salt and from the point so obtained draw a tangent to the curve. This tangent is the locus of minimum potential (stable systems) for any composition. At the point a for example, we have a saturated solution containing the number of gr.-mol. of solvent indicated by the corresponding abscissa and the proportion $\frac{ac}{cb}$ of salt, the balance of the salt remaining in solid phase. At b we have the saturated solution with all the salt included; to the left of b upon the curve, supersaturated solution; and to the right unsaturated solution. With increase of temperature the form of the curve changes and c approaches d, the melting point of the salt.

These types are for the moment purely hypothetical and are a product of the method of analysis, though they are being rapidly identified for various isomorphous pairs by pupils of Roozeboom and by others.

The method of reasoning which yields these three possible types will be briefly described with the help of the van Alkemade graphical analysis:

If we indicate the potential (ζ) of a particular mixture by the length of the ordinate (fig. 16), and the number of molecules of A and B by subdividing the horizontal axis ($A+B=100$) in the proper proportion, assuming atmospheric pressure and constant temperature for each diagram, then every point within the coördinates represents a particular phase of known composition and potential. Suppose now (Roozeboom) a temperature is assumed above the melting point of the higher-melting component, clearly, whatever the composition, only the liquid phase can have a stable existence. If potential difference represents the measure of the tendency to change and the tendency of all change is toward the minimum potential, for this temperature all change will be toward the liquid, and the potential of a solid, if one existed there, would be greater than that of the liquid for all compositions —hence the curve S (solid) above the curve L (liquid) throughout.

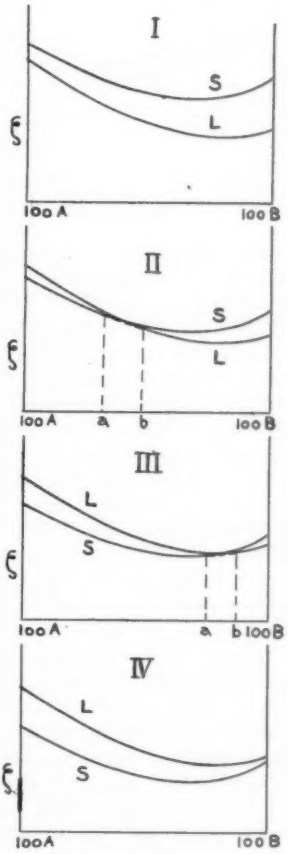


FIG. 16.

Suppose the potential to be lowered to a point where crystallization can begin, the tendency to melt no longer obtains for all compositions, the two curves will be displaced relatively and, being of different form, will intersect. Draw a common tangent to the two curves and apply van Alkemade's reasoning above noted. The trend of the potential of both phases between the points of tangency, i. e. of all mixtures between these limits of composition, is toward the minimum represented by this tangent. Crystallization will then begin at *a*

(fig. 16, II) with the mixture richest in the higher melting component, crystals of composition *a* will be in equilibrium with the liquid phase *b* in all proportions and solidification (or melting) will not take place at a single temperature but through a range of temperature. If we now plot the length of the abscissa corresponding to *ab* in a separate diagram with the observed temperature range of solidification, adding all the other possible cases which will arise from the continued displacement of the ζ-curves, we arrive at the accompanying diagram (fig. 17) of Roozeboom's type I. Types II and III appear in the same way when the form of the ζ-curves changes as indicated in figs. 18 and 19.

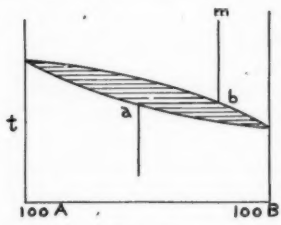
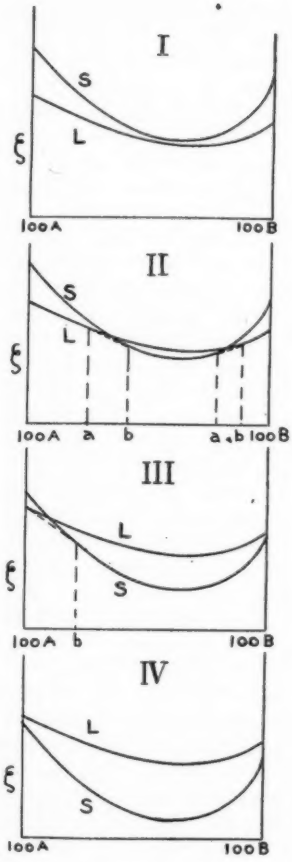


FIG. 17.

The physical side of the system of reasoning is readily inferred from the figures. If we start with a mixture of the composition indicated by *m*, (fig. 20) and temperature above the melting point, crystallization will begin at *a*, the separating crystals will have the composition *b*, while that of the remaining melt approaches *d*. Upon cooling to *e*, solidification ends with crystals of this composition. Melting is exactly the reverse operation. Whether these first crystals of composition *b* remain stable as such or undergo solid transformation or wholly or partly redissolve, appears to remain undetermined in any general way by Roozeboom's theory and may be radically influenced by accompanying phenomena like viscosity and undercooling: if a liquid mixture of composition *a* undercools to *e* before crystallization begins, crystals of composition *e* will appear *and no others* (provided the release of heat of fusion does not raise the temperature above *e*). Such a situation is certainly unavoidable in viscous mixtures like the feldspars and accounts very well for the homogeneous solidification observed by us. This would classify the feldspars with type I of Roozeboom's series. A comparison of our melting point curve with figs. 17, 18 and 19 shows this to be the only type under which it could possibly fall. There is no trace of a maximum or minimum in the feldspar curve. Vogt's expectation that they would fall under type 3 therefore fails of fulfilment from our experiments.

That our curve so closely resembles one branch of Roozeboom's typical curve is remarkable. The difficulties of observation, in those portions of the curve where the viscosity becomes so disturbing, are too great to enable stress to be laid upon the form which our curve happens to take there, but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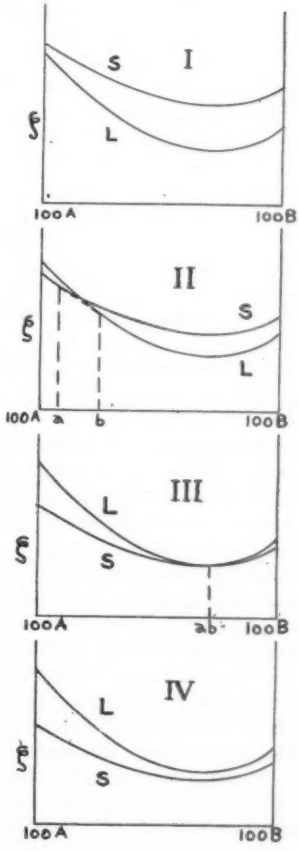
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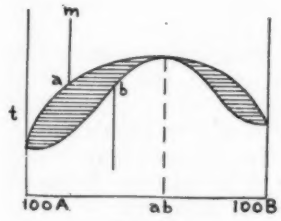
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Fig. 18.

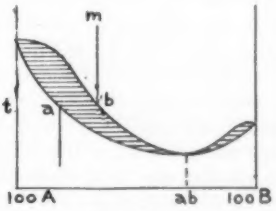
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Fig. 19.

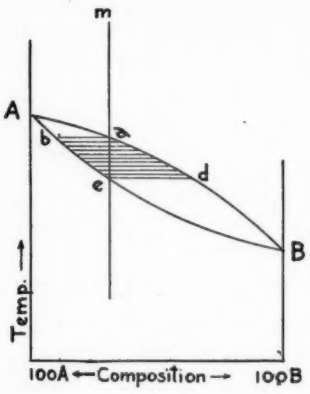


FIG. 20.

near the anorthite end of the series its slight convexity is unquestionably real.

It should be added that Prof. Iddings has found slight traces of inhomogeneity (less than 1 per cent) in the slides of several of our intermediate feldspars. Crystals have been found which were evidently of the earliest formation and with one exception were more calcic than the body of the charge, as Roozeboom's theory would lead us to expect. The exception was an occurrence of tiny plates of Ab_4An_1 discovered in a charge of Ab_1An_2. The extremely small quantity of the optically different feldspar, the fact that it could not be found in all the slides and that in one case a less calcic feldspar appeared, suggest that the inhomogeneity may have been of other origin—perhaps merely a consequence of the tremendous difficulty in mixing a homogeneous charge where ultraviscosity precludes stirring, for example. The chemical analyses of the solid and liquid phases, it will be remembered, showed identical composition within the limits of experimental error.

It is clear that if Roozeboom's theory is valid, the line of the melting points can not become perfectly straight unless the ζ-curves for the solid and the liquid phases can be superposed point for point throughout, i. e., are identical. This would mean that the energy content per gr.-mol. of solid and liquid phase was the same for all compositions, i. e. that all mixtures, and the components separately should have the same melting point,—a case which is known (Roozeboom, *d*- and *l*-camphor oxime) but is certainly confined to optical antipodes.

Another reason for supposing the case to be much less simple than a mere linear relation with equilibrium between solid and liquid phases of identical composition, appears at once from a direct application of the phase rule. A necessary condition for equilibrium in any mixture is that the number of phases exceed the number of components by two. If the solid and liquid phases are homogeneous, the number of phases (counting vapor) is only three and equilibrium can not obtain there.

Reviewing this discussion briefly: The triclinic feldspars are solid solutions and form together an isomorphous series. It is a sufficient condition for the latter that the curve of melting points is continuous (Bruni, loc. cit.). Like Küster's

curves for organic compounds, the curve of melting points does not follow van't Hoff's law of dilute solid solutions and does approximate closely to a straight line joining the melting points of the components. The case appears to fall under type 1 of Roozeboom's theoretical classification of isomorphous mixtures, in which case the line can not become exactly straight unless the melting points of the components are nearly or quite identical, nor the solidification absolutely homogeneous without reducing the number of phases to three and destroying the equilibrium. The theory also accounts for an absence of sharpness in the intermediate melting points of the feldspars, but the fact that this lack of sharpness culminated in albite instead of terminating there shows that the viscosity was the chief factor in our difficulties from this cause. Albite was clearly shown to melt through a variable range of 150° or more, while the intermediate feldspar bytownite (Ab_1An_2) melted almost as sharply as anorthite. The fact that practically no differences of composition could be detected in our melts we attribute to the effect of viscosity and consequent undercooling, which resulted in crystallization invariably taking place at much too low a temperature for equilibrium to become established between the solid and liquid phases at any stage of the crystallization process.

(2) When the specific gravities are plotted, like the melting points, as a function of the composition (fig. 21), the isomorphism of the feldspars is strongly confirmed. The curve indicates a perfectly continuous relation which the successful preparation of chemically pure albite enabled us to follow through to the end. The order of accuracy is also extraordinarily high throughout by reason of the chemical purity of all the preparations and the consistent effort made to obtain complete crystallization, even with the more viscous feldspars. Several of the charges were treated for two weeks or more consecutively, then removed for a determination, then replaced in the furnace for another week, in order that we might assure ourselves from the consistent reappearance of the same value that a maximum and therefore holocrystallization had been reached. It is of some practical importance to note in passing, that preparations which appeared completely crystalline in the slides frequently proved not to have reached their maximum specific gravity. It is very difficult to detect the last trace of glass with the microscope.

If our confidence in these determinations is justified, the form of the specific gravity curve is very significant. It was pointed out by Retgers* that if the isomorphous mixture is merely a "mechanical aggregate," the volume of which remains exactly equal to the sum of the volumes of the components, then the specific volume curve of the mixtures for percentages by weight

* J. W. Retgers, Zeitschr. für Phys. Chem., iii, p. 507, 1889.

of the two components must be a straight line. He also offers a number of isomorphous pairs for which he finds the specific volume curves to be straight lines, in support of his hypothesis that this relation is general. Our values when plotted in this way (fig. 22) also give a straight line with maximum variations amounting to 0·005, which is probably not greater than the aggregate error in the syntheses and in the determinations of the specific gravity.

In spite of this apparent corroboration, it does not seem to us that Retgers was quite justified in assuming that this relation is entirely without limitation. The temperature at which the specific gravity is determined is so far below the temperature of solidification (in our case, more than 1,000°) that the density at 25° will depend to a considerable degree upon the coefficient of expansion of the material as well as upon composition or molecular structure. The coefficient of expansion will, in general, differ for different substances, and is not, in general, a linear function of the temperature. Considering Retgers' generalization in the light of these facts, the relation of the specific gravities at 25° would be necessarily continuous but not necessarily linear.

The specific gravities of the glasses are also plotted (fig. 21) to show the divergence from the line of the crystals toward the albite end of the series, i. e., as the percentage of albite increases, the density of the glass is diminished more than that of the crystals.

There is nothing new in the conception of isomorphism in the feldspars, but the positive character of our experimental results makes them of more than ordinary interest by reason of the fact that so good authorities on the subject as Fouqué and Lévy have passed upon it adversely on the basis of optical evidence derived from artificial preparations. More recently Viola,* has declared that the optical evidence is insufficient to prove isomorphism in the natural feldspars.

The melting points and specific gravities are brought together in a convenient table here.

Feldspar	An	Ab_1An_5	Ab_1An_2	Ab_1An_1	Ab_2An_1	Ab_2An_1	Ab
Melting temp.	1532°	1500°	1463°	1419°	1367°	1340°	
Sp. gr. (crystals)	2·765	2·733	2·710	2·679	2·660	2·649	2·605
Sp. gr. (glass)	2·700	2·648	2·591	2·533	2·483	2·458	2·382

(3) In the melting of albite and microcline we appear to have substantial evidence of a phenomenon which is unfamiliar both to physics and to mineralogy. Microscopic crystals of a homogeneous compound, when slowly heated, were shown to persist for 150° or more above where melting began, the amorphous melt remaining of the same order of viscosity as the rigidity of the crys-

* Loc. cit.

tals. By careful observation, curves were also obtained showing that the absorbed heat of fusion was distributed over this interval.

From the experimental standpoint a substance of this kind can hardly be said to have a melting point but passes gradually from crystalline to amorphous at temperatures which can be

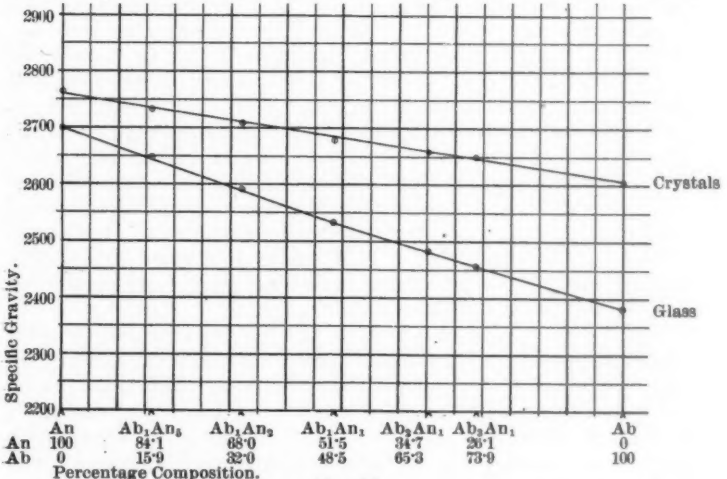


FIG. 21.

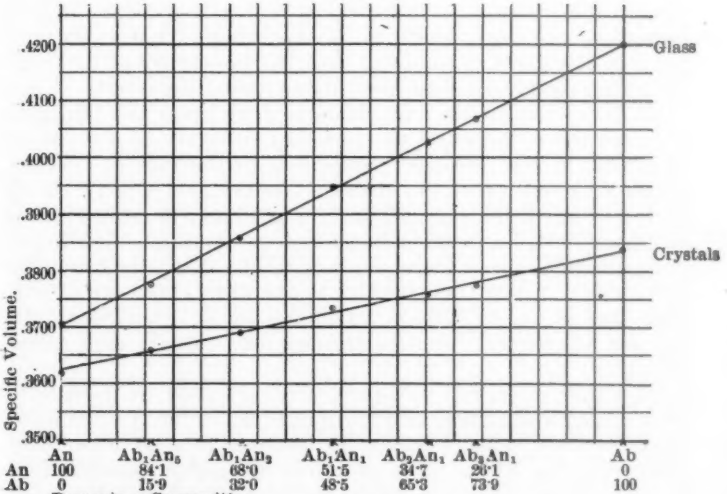


FIG. 22.

considerably varied by merely changing the rate of heating. In moderate charges of albite or orthoclase at atmospheric pressure this melting began so slowly that it was not possible to locate even approximately a lowest temperature for the beginning of the change of state. As a matter of definition, this minimum temperature above which melting will continue (for a given pressure) more or less rapidly according to the conditions, is the "melting point," whether it can be located or not, so far as the equilibrium of the system is concerned, and the crystals which continue to exist unmelted at higher temperatures appear to form a metastable phase, perhaps comparable with that of a crystalline solid when heated above the "Umwandlungstemperatur" without immediate change of crystal form. It is also possible that the mass is fluid when heated above the melting point but that deorientation of the molecules is delayed by viscosity. This metastable stage can easily extend over 150° in albite and orthoclase and would persist for days in the lower position of this range.

(4) We also found that viscous and poorly conducting melts which solidify only after considerable undercooling, do not give constant solidifying points. The solidifying point must not be used, therefore, without great caution as a physical constant; it bears no relation whatever to the melting point unless equilibrium is reëstablished before solidification is complete—a condition which rarely obtains and often can not be produced in viscous mineral melts. Especial attention is directed to this because of the importance of the lowering of the solidifying point in the study of solutions, and the possibility of its application to mineral solutions recently suggested by Vogt.*

(5) Incidental to the experimental work upon the feldspars we were able to establish the fact that there are no differences of density in the feldspar glasses due to the rate of cooling, which are greater than our errors of observation (±·001). Also that powdered feldspar glasses sinter tightly at temperatures as low as 700°,—a phenomenon which we ascribe to flow in the undercooled liquid. Pure, dry, crystalline feldspars also sinter at least 150° below their melting temperature, but very slowly. This may be due to certain crystalline nuclei growing at the expense of others; perhaps through exceedingly slow sublimation.

Also that powdered feldspars, when exposed to the atmosphere, adsorb moisture, in quantities of an order of magnitude equal to those usually quoted in analyses (Dana's System of Mineralogy, p. 314). It is therefore altogether possible that the significance of this moisture has been mistaken. It cannot be completely driven off below a red heat.

Geophysical Laboratory, Carnegie Institution,
Washington, D. C., November, 1904.

*J. H. L. Vogt, loc. cit.

Art. VIII. — *On the Progress of the Albatross Expedition to the Eastern Pacific;* by Alexander Agassiz.

[Extract from a letter to Hon. George M. Bowers, U. S. Fish Commissioner, dated Lima, Nov. 28, 1904.]

The Albatross, under command of Lieut. Commander L. M. Garrett, left San Francisco on the 6th of October and arrived at Panama the 22d. On her way along the coast Professor C. A. Kofoid took advantage of the opportunity for making surface hauls with the tow nets as well as vertical hauls, generally to a depth of 300 fathoms. A large amount of pelagic material was thus collected, not at a great distance from the coast however. Off Mariato Point the Albatross made two hauls in the vicinity of the stations where in 1891 she found "modern green sand," in about 500 and 700 fathoms. It was interesting to find the green sand again, as the specimens collected in 1891 were lost in transit to Washington. I am fortunate in having as assistant for this trip Professor Kofoid, who has had great experience in studying the Protozoa both in fresh water and at sea. He has been given charge of the collection of Radiolarians and Diatoms and of other minute pelagic organisms; and he will prepare a report on the results of that branch of the Expedition.

The Albatross arrived at Panama on the 22d, she was coaled and provisioned at once, on my arrival at Panama on the 1st of November I found her ready for sea, and on the 2d we left for Mariato Point to make a few additional trawl hauls in the region of the green sand. In both the hauls made off Mariato Point green sand was found, but not in the quantity obtained in 1891.

From Mariato Point we made a straight line of soundings towards Chatham Island in the Galapagos, intersecting the ring of soundings we made northeast of the Islands in 1891. The deepest point of the line (1900 fathoms) was found about 100 miles S.W. of Mariato Point. The bottom then continued to show about 1700 fathoms for nearly 200 miles and then shoaled very gradually to 1418 fathoms about 80 miles from Chatham Island. From this point it sloped quite rapidly, the 1000-fathom line being not more than 60 miles from Chatham Island. We ran a short line south of Hood Island and found a somewhat steeper slope to that face of the Galapagos, reaching over 1700 fathoms in a distance of less than 50 miles; the bottom then remained comparatively flat, attaining a depth of 2000 fathoms about 100 miles farther south. This depth we carried eastward on a line to Aguja Point. When half way the soundings had increased to over 2200 fathoms, and remained at about that depth to within 60 miles of the

coast, when the depth rapidly shoaled. From Aguja Point we ran a line of soundings to the S.W. to a point about 675 miles west of Callao; on this line the depths gradually increased from 2200 fathoms, 100 miles off the Point, to nearly 2500 fathoms. On running east to Callao the depth soon increased to about 2600 fathoms, and at a distance of about 80 miles off Callao we dropped into the Milne-Edwards Deep and found a depth of over 3200 fathoms. We spent a couple of days in developing this Deep, making soundings of 1490, 2845, 458, 1949, 2338, and 3120 fathoms; showing a great irregularity of the bottom within a comparatively limited area of less than sixty miles in diameter. Thus far all our soundings have been made with the Lucas Sounding Machine.

In the Panamic Basin to the northeast of the Galapagos we trawled only off Mariato Point, but we occupied ten stations with the tow nets, hauling both at the surface and at 300 fathoms, and vertically from that depth; we also continued this pelagic work at nearly all the stations (35) from the Galapagos to Callao.

When off Chatham Island we began to trawl, and used the tow nets regularly, occupying 20 stations. The nets were in charge of Mr. F. M. Chamberlain. The pelagic collections, as a whole, are remarkably rich. They are especially noteworthy for the great variety and number of pelagic fishes obtained inside the 300-fathom line at a considerable distance from shore —from 300 to 650 miles. Many of these fishes had been considered as true deep-sea fishes, to be obtained only in the trawl when dredging between 1000 and 1500 fathoms or more. On one occasion the tow net brought up from 300 fathoms, the depth being 1752 fathoms, no less than 12 species of fishes; of some species of Myctophum we obtained 18 specimens; of another, 37; of a third, 45; in all nearly 150 specimens. On other occasions it was not uncommon to obtain 8 or 10 species, and from 50 to 100 specimens. Among the most interesting types obtained in the tow net I may mention as coming from less than 300 fathoms Stylophthalmus and Dissoma, both of which Chun considers as deep-sea fishes, found in depths of 600 to 4000 meters; also a species of Eurypharynx obtained for the first time in the Pacific. Stylophthalmus I had caught in the tow net also in 1900, during the tropical Pacific Expedition of the Albatross, in depths of less than 300 fathoms. In the lines we ran across the great northerly current which sweeps along the coasts of Peru and Chili and is deflected westward at the easterly corner of the Galapagos Islands, we obtained with the tow nets an unusually rich pelagic fauna at depths less than 300 fathoms. We collected a number of Schizopods, among them many beautifully colored Gnatheuphausiæ, pelagic Macrurans; huge, brilliant red Copepods, as well as many other species of blue,

gray, mottled and banded Copepods. Lucifer and Sergestes were abundant in many of our hauls. Many species of Amphipods were collected, Hyparids without number, especially where the surface hauls were made among masses of Salpæ, which, on several occasions, formed a jelly of Tunicates. Several species of Phronimæ also occurred constantly in the tow nets. Sagittæ were very numerous, a large orange species being noteworthy. Several species of Tomopteris, some of large size and brilliantly colored, violet or carmine with yellow flappers, and two species of Pelagonemerteans. Two species of orange-colored Ostracods were also common, one having a carapace with a long spiny appendage. We obtained several species of Pelagic Cephalopods, Cranchia and Taonis among them. Two species of Doliolum also occurred, but they were never as abundant as the Salpæ, two species of which often constituted the whole contents of the net.

In the surface and deeper tows we procured also a number of Acalephs. We have thus far collected more than 50 species of Medusæ and Siphonophores, many of which have been figured by Mr. Bigelow, differing from those of the 1891 Expedition. Atollæ and other deep-sea Medusæ were common within the 300 fathom line.

The Salpæ guts gave us, in addition to the finer tow nets, immense collections of Radiolarians, Diatoms, and Dinoflagellata, many of which have been considered to live at great depth and upon the bottom. The number of Diatoms found in this tropical region is most interesting. They have usually been considered as characteristic of more temperate and colder regions. On several occasions the surface waters were greatly discolored by their presence, and the extent of their influence on the bottom deposits is shown by the discovery of a number of localities where the bottom samples at depths from 1490 to 2845 fathoms, in the track of the great Peruvian current, formed a true infusorial earth.

The tow nets also contained many species of Hyalea, Cymbulium, Styliolus, Cleodora, Tiedemannia, Clio, and the like. On one occasion the mass of the pelagic hauls consisted entirely of small brown Copepods, the contents of the tow nets looking like sago soup. Another time Sagittæ, Salpæ, Diliolum and Liriope, all most transparent forms, formed the bulk of the tow net's catch. Again another time, Firoloides and Carinarias constituted the bulk of the haul. These catches, coming on successive days or interrupted with hauls of more than mediocre quality, show how hopeless it is at sea to make any quantitative analysis of the pelagic fauna and flora at any one station within the influence of such a great oceanic current as the Chili and Peruvian stream.

Hauls of the trawl made at the western extremity of our lines brought us within the area of the manganese nodules, with its radiolarian ooze mud, Cetacean earbones and beaks of Cephalopods; nothing could stand the damaging work of these nodules in grinding to pieces all the animal life the trawl may have obtained. Down to the depth of 2200 fathoms or so the bottom was constituted of Globigerina ooze, its character being more or less hidden when near the coast by the amount of detrital matter and terrigenous deposits which have drifted out to sea.

North of the Galapagos we found vegetable matter at nearly all the stations, and between the Galapagos and Callao such material was not uncommon in the trawl.

Beyond the line of 2200 fathoms dead Radiolarians became quite abundant on the bottom, as well as in the mud of the manganese nodules, though among the nodules it was not uncommon to find an occasional Biloculina. Many of the dead Radiolarians found on the bottom Mr. Kofoid obtained from the guts of Salpæ swimming near the surface or within the 300 fathom line in the tow nets sent to that depth. The same is the case with many of the Dinoflagellata which have been considered as deep-sea types. In our tow nets from 300 fathoms we found very commonly Tuscarora, Tuscarosa, Aulospira and others. In depths of 300 fathoms to the surface, the tow net was rich in Tintinnidæ, either dead or moribund Planktionellæ, and Dinoflagellata. Among the Dinoflagellata there were 10 species of Ceratium, 9 of Peridinidæ, Goniaulix, Phalacrona, Pyrocystis, Cytterocyla, Undella and Dictiocystus. On the surface Planktionella sol predominates, with Asteromphale, Bidolphia, and Sunidia thalassothrix. Among the Dinoflagellata we obtained 12 species of Ceratium, 5 of Peridinium and 22 species of other Peridinidæ; among the Tintinnidæ were a number of Stichologa; among the Acantheriæ were especially to be noticed Acanthometra, Acanthostaurus, Amphilonche, Collozoum, Thalassicola, and a number of Chirospira Murrayana and a few Challengeridæ.

Our trawls brought up from the bottom many interesting fishes, among which I may mention Benthoptemis, Ipnops, and a few bat fishes, all, thus far, described by Mr. Garman from the 1891 Expedition. I may mention also a Chimæra, different from the Chili species. The fishes have been admirably cared for by Dr. J. C. Thompson, U. S. N.

Among the Crustacea, Lithodes, Munidopsis and many Macrurans, all well known species of the 1891 Expedition, we found a few Mollusks, and a few interesting genera of Tubiculous Annelids. Compared to the 1891 Expedition, few starfishes and brittle stars were obtained, and still fewer Sea Urchins, only one species of Aceste and one of Aerope, a

marked contrast to the numerous Echini collected in the Panamic Basin in 1891. We obtained, however, a magnificent collection of Holothurians, nearly every species occurring in the Panamic Basin being found in numbers in our track south of the Galapagos, in the wake of the great Chili-Peruvian current and at considerable depths. On one occasion, at station 4647, in 2005 fathoms, we obtained no less than 16 species of Holothurians, among them brilliantly colored Benthodytes, Psychropotes, Scotoplanes, Euphronides, and the like. At station 4670, in 3209 fathoms, we obtained 6 species of Holothurians. At station 4672, in 2845 fathoms, we obtained also very many specimens of three species of Ankyroderma, a large Deima, 2 species of Scotoplanes, 2 of Psychropotes, with a number of young stages of that genus, repeating thus the experience of the Challenger, which found Holothurians at great depth, in abundance not only in the number of specimens but also of species, though the Challenger did not in any locality obtain as many as we did at station 4647. Mr. Westergren made a number of sketches of the species which were not obtained in the 1891 Expedition. We also collected in the trawl a number of deep-sea Actinians, none different, however, from genera previously found in the Panamic district. We obtained also a few Pennatulids, Gorgonians, and Antipathes, and a very considerable number of silicious sponges, usually associated with the Holothurians found in deep water in the track of the Peruvian current. In the track of the current at not too great distances from the coast we invariably brought, even from very considerable depths, sticks and twigs and fragments of vegetable matter. On two occasions we brought up in the trawl specimens of Octacnemus. The trawl had been working at 2235 and at 2222 fathoms. Both Moseley and Herdman described this interesting Ascidian as attached to the bottom by a small peduncle. While the presence of the peduncle cannot be denied, yet its attachment, if attached at all, must be of the slightest, its transparent, slightly translucent body, with its eight large lobes, suggesting rather a pelagic type than a sedentary form. This Ascidian was discovered by the Challenger west of Valparaiso.

Mr. Chamberlain made two daily observations of the density of the water, and found the same discrepancies between our observations and those of 1891, and those given by the Challenger and in the German Atlas of the Pacific Ocean. Whenever we took a serial temperature, he also determined the density at 800 fathoms. We occupied six stations for the serial temperatures, two on the western termini of the lines normal to the coast across the great Peruvian current, two in the center of the current, and two at a moderate distance from the coast. These serials developed an unusually rapid fall in the tem-

perature between the surface and 50 fathoms—nearly 12° at the western extremity of the northern line, the temperature having dropped from 71·7° at the surface to 59·2°. At 200 fathoms it was 51°, and at 600 fathoms it had dropped to 40·7°, the bottom temperature at 2005 fathoms being 36·4°. The temperature of the station in the central part of the current in 2235 fathoms agreed with the western series. At the eastern part of the line in 2222 fathoms, with a bottom temperature of 36·4°, the surface being only 67°, we found again a close agreement at 50 and 100 fathoms, the lower depths at 400 and 600 fathoms being from one to two degrees warmer than the outer temperatures. On taking a serial from the surface to 100 fathoms, we found that the greatest drop in temperature took place between 5 and 30 fathoms.

The temperatures of a line running due west from Callao showed a very close agreement both at the western end of the line about 780 miles from the coast and in the central part of the line, as well as in the shore station about 80 miles from the coast in 3209 fathoms. The bottom temperature in nearly all the depths we sounded was 36°, a high temperature for that depth. I do not make at present any comparison with the serials taken in the Panamic District in 1891 until we shall have completed our lines to the south and to the west.

We leave for Easter Island on the 3d of December, where we shall coal, and from there go to the Galapagos and thence to Manga Reva and Acapulco, where we ought to arrive in the early days of March.

The changes made in the working apparatus of the Albatross under the superintendence of Lieutenant Franklin Swift, U. S. Navy, have proved most satisfactory. The alterations in the main drum and the device for preventing the piling of the wire on the serging drum and the accompanying shock, have greatly reduced the risk of breaking the wire rope when trawling at great depths. The wire rope has proved an excellent piece of workmanship, and has worked admirably in the comparatively deep water in which most of our trawling has been done thus far. A new dredging boom has also been installed, and everything relating to the equipment of the Albatross has been carefully overhauled.

Lieut. Commander L. M. Garrett has been indefatigable in his interest for the Expedition; the officers and crew have been devoted to their work; and the members of the scientific staff have carried out most faithfully their duties of preparing and preserving the collections thus far made.

We hoped to be docked at Callao, but owing to the prolonged occupation of the dock by a disabled steamer and the uncertainty of its becoming free within reasonable time, we decided to proceed without further delay to Easter Island and continue the Expedition as we are.

Art. IX. — *Measurement of Self-Inductance;* by J. B. Whitehead and H. D. Hill.

The absolute measurement and comparison of self-inductance has within the last few years become a problem of increasing importance. The best known method and that most generally used is the Rayleigh method. However, this necessitates very intelligent and careful work to obtain results concordant to one per cent. What seem to be the most accurate methods are various modifications of the Wheatstone bridge using alternating currents with an electrodynamometer, telephone, or optical telephone as the measuring instrument.

In January, 1898, Professor Rowland* published a brief description of some twenty-six methods for the measurements and comparison of self-inductance capacity and mutual inductance. These methods are mostly of the Wheatstone bridge type and depend upon the use of an alternating current and an electrodynamometer. As only a few of them have hitherto been tried, it was deemed desirable to systematically test them and determine their value, particularly in regard to the measurement of self-inductance. Such is the aim of the present investigation.

Source of current and frequency determination.

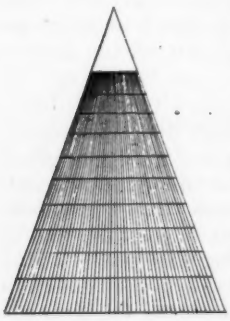
Since the value of the self-inductance or capacity as given by many of the methods depends upon the square of the current frequency, it was necessary to secure a current of harmonic wave form whose period was as constant as possible, and to devise a method of accurately determining that period at the moment of adjustment. This was very satisfactorily accomplished. In the deduction of the formulæ for all the methods the assumption is made that we have a simple harmonic electromotive force. In general an alternating current supplied by a dynamo has not only its fundamental period but also the odd upper partials. However, a generator constructed without too much iron and properly wound, if the field is not very strongly excited, will give a very good sine wave; especially if the resistance in the circuit contains self-inductance and no iron. These requirements were well satisfied by the dynamo used, which gave a very good sine wave. The alternator was constructed at the University. Its armature consisted of twelve coils fastened flat on a German silver plate revolving between twelve field pieces producing six poles. This dynamo was coupled directly to a direct current Crocker-Wheeler

* Phil. Mag. [5], xlv, 66–85, 1898.

motor. As long as the load on the dynamo was not varied the speed remained very constant. Greater constancy of speed was secured by operating the motor from storage batteries. The voltage furnished by the alternator could be controlled by slightly altering the strength of the field. For the determination of the frequency a chronograph was used. A kind of speed counter was connected to the shaft of the dynamo and a contact so arranged that in every ninety-seven revolutions of the dynamo armature a circuit was closed and a record made on the chronograph sheet. The chronograph was set up close to the rest of the apparatus and by means of a thread the pen could be raised for an instant from the sheet and so the exact time of making an adjustment could be readily noted. By interchanging the gear wheels the cylinder of the chronograph was made to run at about three and one-half times the customary speed. The distance between the checks indicating the seconds was so increased to over five and one-half centimeters.

A scale similar to that shown in fig. 1 was then constructed, consisting of fine lines scratched on transparent celluloid and blackened with India ink. By means of this scale it was possible to read the chronograph sheet directly to fiftieths of a second and to estimate to five hundredths. However, in reading a chronograph sheet as exactly as this, certain precautions must be taken. First, the checks indicating the seconds should be sharp and distinct. Secondly, an error may arise if the chronograph does not run quite regularly. This can generally be remedied by properly adjusting the governor. By this method the frequency could be quite accurately determined, to 1/10 per cent or closer, if the sheet was read with sufficient care. It is to be noted that if sidereal seconds are recorded on the chronograph sheet they should be reduced to solar seconds, otherwise an error of 3/10 per cent is introduced in the absolute value of the frequency and, therefore, of 6/10 per cent in the value of self-inductance.

1



Apparatus.

Electrodynamometer.—A Rowland electrodynamometer was used. The self-inductance of the fixed coils was ·0165 henry, and of the hanging coil ·0007 henry.

Resistances.—In the measurements of self-inductance with alternating currents, ordinary resistance boxes are of little or

no value owing to the electrostatic capacity of the doubly wound coils. Except in the case of a few determinations with Method 25, all the resistances used were made of a special German silver resistance wire, B. and S. gauge, Nos. 30 and 27. This wire was not doubled, but wound continuously in one layer on slates or pieces of micanite, each slate containing about 2000 ohms conveniently subdivided. The self-inductance and capacity of such resistances is entirely negligible. For fine adjustment a small resistance box was constructed differing from an ordinary box in that its coils were wound flat on thin pieces of micanite.

Coils and Condenser.—The coils whose inductance were measured were as follows:

P, external diameter 33·46^{cm}, internal diameter 23·8^{cm}, was made of about 1200 turns of No. 16, B. and S. gauge single cotton-covered copper wire. Self-inductance as determined, ·5729 henry. Resistance, 36·3 ohms.

C. Same dimensions as P except depth. It consisted of 1747 turns of No. 22 B. and S. gauge single cotton-covered copper wire. Self-inductance found to be 1·3025 henry. Resistance, 78 ohms.

S. External diameter 23·5$^{cm^2}$, internal diameter 15^{cms}, depth about 3·5^{cms}. It consisted of 2082 turns of No. 22 B. and S. single cotton-covered copper wire. Resistance, about 69 ohms. Self-inductance found to be 1·0331 henrys.

Condenser.—A $\frac{1}{2}$ microfarad mica condenser.

Conditions of sensibility.—The deflection of an electrodynamometer is proportional to the product of the currents flowing in the fixed and hanging coils multiplied by the cosine of the phase difference of the two currents. In most of these Rowland methods the adjustment consists in so altering non-inductive resistances in one or more branches of the bridge that there is a ninety degree phase difference between the currents in the fixed and hanging coils respectively. Evidently in order to secure maximum sensibility the currents through the dynamometer coils should be as heavy as possible, heating alone being the limit.

Sources of Error.—In work with alternating currents great care must be exercised that one part of the network does not exert an inductive action on another, e. g., that the coil whose inductance is being measured does not affect the hanging coil of the electrodynamometer. Induction was carefully guarded against by the arrangement and tested for by means of reversing switches. The electrostatic capacity of doubly wound coils and resistances has already been mentioned as well as the precautions taken to avoid it. In the experiments here described all the connections were made as short as possible and no wires were twisted. Heating of the resistances was avoided as much

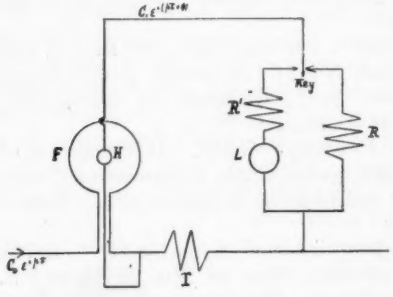
as possible and in the more accurate work the resistances of the several arms of the network were measured after adjustments on a Nalder standard "Post Office" box. All resistances are in International ohms.

Methods Used.

I.

Method 25.—The first method tried was that designated in Professor Rowland's article as number 25. It is an absolute method intended for the measurement of either self-induction or capacity, the value of which depends upon the square of the current frequency. It was given a thorough test by Dr. T. D. Penniman,* except in so far as his method of measuring the frequency was rough compared with that used in this investigation, and he ascribes the lack of uniformity of his results chiefly to a want of knowledge of the current period. It was therefore thought well to give the method a hasty trial in regard to the measurement of self-induction. In this method the hanging coil is shunted off the fixed coils circuit and the deflection with a non-inductive resistance in circuit with the hanging coil is made the same as that of an inductive resistance in circuit with the hanging coil. The method and connections are shown in figs. 2 and 3; F and H represent the fixed and hanging coils of the electrodynamometer; R, R′ and r, the total resistances of the three branches; L is the self-inductance of the coil to be measured, W is a reversing commutator. The formula for the method as deduced by Dr. Penniman is,

2



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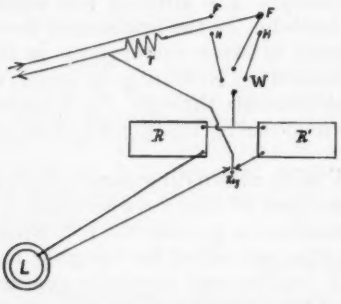


$$p^2 L' = (R' - R)(R + r)$$

where p is equal to 2π multiplied by the current frequency.

* This Journal, viii, p. 35, 1899.

This method did not prove satisfactory for measuring self-inductance. With care it is possible to obtain values which do not differ among themselves by more than 1 per cent. One drawback to the method is its lack of sensibility, that is, it is not usually possible to adjust the resistances closer than one part in three hundred. Again, since the electrodynamometer was very "dead beat" it required a certain small time to compare the deflections, to be sure not long, but enough for the current period to alter slightly unless special precautions were taken. A few determinations of the self-inductance of coils S and C are given. It will be noticed that the values are lower than those obtained later by a more accurate method. This is probably due to the use of ordinary resistance boxes possessing electrostatic capacity. This method was the first tried and is the only one in which such resistances were used.

TABLE I, Coil C.

Zero.	Deflection.	R.	R'.	r.	n.	L.
24·98	15·30	149·7	1513·7	4·017	57·567	1·266 henrys
"	15·49	"	1531·7	"	57·227	1·282 "
24.82	15·18	"	1518·7	"	57·453	1·271 "
"	15·11	"	1530·7	"	57·510	1·275 "
24·77	12·70	199·7	1241·7	"	57·453	1·276 "
24·73	12·62	"	1238·7	"	57·510	1·273 "
					Mean	1·274 "

TABLE II. Coil S.

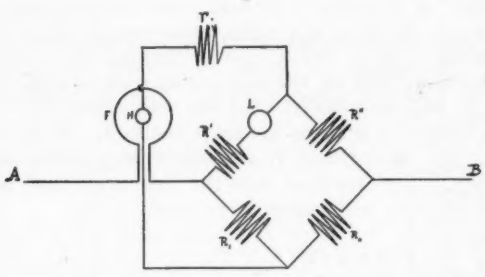
Zero.	Deflection.	r.	R.	R'	n (cycles).	L (henrys)
240·0	158·2	4·017	141·5	1300·7	63·885	1·023
"	158·5	"	"	1283·7	63·62	1·021
"	"	"	"	1283·7	63·329	1·020
239·2	301·0	"	"	1288·7	63·261	1·028
"	"	"	"	1281·7	"	1·025
239·0	134·2	"	191·5	1041·7	64·095	1·012
"	134·8	"	"	1038·7	63·955	1·013
238·7	345·8	"	"	1036·7	"	1·012
"	"	"	"	1038·7	"	1·013
249·0	121·3	"	241·5	920·7	64·095	1·014
"	"	"	"	922·7	"	1·015
239·1	129·9	"	291·5	850·7	64·167	1·009
"	"	"	"	"	64·095	1·010
239·7	"	"	491·5	836·7	64·23	1·025
					Mean	1·0171 henry

II.

Method 14.—The next method tested was that which in Professor Rowland's paper is number 14. It is an absolute method for measuring either self-inductance or capacity. It is a zero

deflection method depending upon adjusting the resistances until there is a ninety degree difference in phase between the currents flowing in the fixed and hanging coils of the electrodynamometer. The method was devised and first used by Oberbeck,* later by Troje.† However, the frequency determination of both these investigators was quite crude and, as will be seen from the formula, the value of L or C varies as the square of the frequency. Diagrams of the method and connections are given in figs. 4 and 5. As before, F and H represent the fixed and hanging coils of the electrodynamometer; $R_{,}$, $R_{,,}$, R', R'' and r are the entire resistance of the several branches, L is the self-inductance of the coil to be measured, and l that of the hanging coil of the electrodynamometer, W is a commutator for reversing the current through the hanging coil, S is a switch by means of which the current could be sent through a resistance X in value closely equal to the impedance of the network. The coil L, to avoid any possible effect on the rest of the network or hanging coil of the electrodynamometer, was placed some distance away usually on a level with the hanging and fixed coils and perpendicular to them.

4



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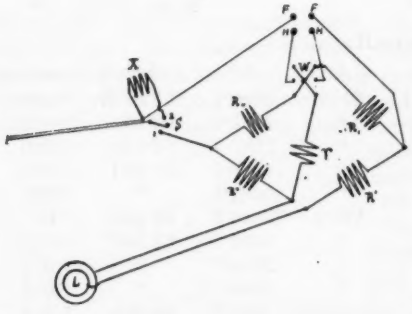


If now an alternating electromotive force be applied to the terminals A and B, we may express the currents in the fixed and hanging coils of the electrodynamometer by $C_0\epsilon^{ipt}$ and $C_1\epsilon^{i(pt+\phi)}$, p being equal to 2π times the frequency. By the application of Kirchhoff's laws to the Wheatstone bridge

* Wied. Ann., xvii, p. 816, 1882. † Ibid., xvii, p. 501, 1892.

using "generalized resistances," we obtain as the ratio of the current in the battery arm to the current the bridge arm,

$$\frac{C_0}{C_1}\epsilon^{i\phi} = \frac{(r+ipl)\,(R_1+R+R'+R''+ipL)\,(R_4+R'')\,(R_1+R'+ipL)}{R_1R''-R_4R'-ipLR''}$$

Multiplying both sides of this expression by C_1^2, rationalizing, and equating the real parts we obtain,

$$C_0C_1\cos\phi = C_1^2\frac{[R_1R''-R_4R']\,[r(R_1+R_4+R'+R'')-p^2Ll+[R'+R_1]\,[R_4+R'']}{[R_1R''-R_4R']^2+p^2L^2R''^2}$$

$$C_1^2\frac{p^2LlR_4\,(R_1+R_4+R'+R'')-p^2L^2rR_4-p^2L^2(R_4+R'')R_4}{R_1R''-R_4R'+p^2L^2R''^2}$$

This expression must be equal to zero since we adjust the bridge until $\phi = 90°$, therefore $\cos\phi = 0$. Equating to zero and simplifying,

$$L^2+Ll\left\{\frac{(R''+R_4)\,(R_1+R_4}{R_4(r+R''+R_4)}\right\} =$$

$$\frac{R'R_1-R_4R'}{p^2R_4}\left\{\frac{r(R_1+R_4+R'+R'')+(R'+R_1)\,(R''+R_4)}{r+R''+R_4}\right\}$$

This formula is somewhat simplified if R_4 is chosen equal to R.″ However, for accurate work the equality must be exact. Since the self-inductance of the hanging coil of the Rowland electrodynamometer is so small, only ·0007 henry, the correction of L due to it is very small, in the case of coil C amounting to ·0004 henry.

In using the method the numerical work involved in the calculation of L is rendered somewhat easier if we write the formula,

$$L+sLl = t$$

when very approximately, since l is so small,

$$L = t+\frac{S}{2}l$$

where

$$S = \frac{(R''+R_4)\,(R_1+R_4)}{r+R_4+R''}$$

and,

$$t = \frac{1}{p^2}\left[R_1\frac{R''}{R_4}-R'\right]\left[R'+R_1+\frac{r(R_4+R'')}{r+R_4+R''}\right]$$

This method was found to be excellent. It is very sensitive and very accurate provided certain precautions are taken. Some little difficulty was experienced at first from the fact that the values of the self-inductance of a coil measured on any one day, although agreeing pretty well among themselves,

differed from those obtained at a different time. The cause of this variance proved to be the heating and consequent lack of knowledge of the resistances. In order to secure sensibility of the electrodynamometer it was the custom to make the current through the fixed and hanging coils quite heavy. Sometimes the current through the fixed coils was nearly $\frac{1}{10}$ ampere. This was unnecessarily large, as with a current of $\frac{1}{20}$ ampere it is easily possible to adjust the resistance to one part in fifteen hundred or two thousand. If we wish to make exact measurements of inductance, the method requires an accurate knowledge of the resistances. To take a specific example, if in the first determination in Table IV we increase R or R″ by 1/20 per cent, a change of −1/3 per cent is introduced in the value of L; similarly changing R or R′ by 1/20 per cent we alter L by +1/4 per cent. In regard to r, L varies only as the first power. Fortunately these errors in L introduced by variation of the resistance are not all of the same sign, and since the current through r must of necessity be quite small (about $\frac{1}{100}$ ampere) the currents through R + R and R′ + R″ are nearly equal. Hence if we assume an increase of all the resistances of 1/20 per cent, the value of L is increased by about one part in one thousand three hundred. Therefore, to obtain the best results with this method we must measure the resistances carefully and avoid much heatings. To avoid heating of the resistances the following plan of taking readings was adopted. The bridge was first adjusted, this being done by altering R′ and R, until on reversing the current through the hanging coil of the electrodynamometer there was zero deflection indicating a ninety degree phase difference between the fixed and suspended coils. By means of the switch S (vide fig. 5) the current was turned through the resistance X, made closely equal to the impedance of the network. This was done to avoid change in the frequency. After a considerable interval, sufficient to avoid the effect of any slight heating in the preliminary adjustment, the current was again switched through the network and R, remaining the same, R′ readjusted to give zero deflection, the exact time of adjustment being noted in the chronograph sheet. This adjustment when made would usually hold good for several minutes. However, it was not usually necessary to run the current through the network longer than twenty or thirty seconds. This process was repeated a number of times with longer or shorter intervals and then the resistances R′ and R, measured. The other arms of the bridge were measured once or twice during the evening; this time was chosen as being free from various disturbances. Generally for several successive observations the same value of R′ would give zero deflection, R, remaining the same. The mean of the frequencies measured for the several observations was taken as being nearest correct.

If, however, R′ had to be altered, the observations were regarded as separate and so worked out.

It was not the purpose of the authors to measure inductance to any great degree of accuracy, but to indicate the possibilities of the methods. Resistances were measured only to about two or three parts in ten thousand on the post office box, which had a considerable temperature correction. Still it will be seen that the determinations of L, except those of coil P, differ from the mean by less than 3/10 per cent.

The measurements of coil P were among the first made with this method, and the resistances were not measured with as much care as in the case of the other coils.

TABLE III.

Oct. 24, 1903.

R_x	R″	r	R_1	R′	n	L
103·75	103·67	425·06	900·76	870·9	65·644	·5722 henry
"	"	"	900·76	870·9	65·614	·5725 "
"	"	"	948·23	919·72	65·763	·5715 "
"	"	"	989·3	961·7	65·763	·5737 "
"	"	"	900·76	870·94	65·614	·5723 "
"	"	"	948·23	918·67	65·614	·5733 "
"	"	"	989·3	961·7	65·614	·5749 "
					Mean	·57291 "

TABLE IV, Coil C.

Dec. 10, 1903.

Temp	R_x	R″	r	R′	R′	n	L (henrys)
16°·3C.	99·907	99·78	968·8	1199·86	1088·6	63·288	1·3044

After the elapse of some minutes.

"	"	"	"	1199·86	1088·6	63·288	1·3044

Dec. 13, 1903.

15°·0	99·94	99·42	968·9	1200·47	1088·0	62·366	1·3055
"	"	"	"	"	"	62·446	1·3008
"	"	"	"	"	"	62·259	1·3047
"	"	"	"	"	"	62·206	1·3058
					Mean		1·30257

TABLE V, Coil S.

Nov. 13, 1903.

R_x	R″	r	R_1	R′	n	L (henrys)
100·0	100·0	425·06	1815·5	1767·2	65·393	1·0309
"	"	"	"	1766·67	65·393	1·0366
"	"	"	1862·9	1815·5	65·688	1·0303
"	"	"	1904·0	1856·96	66·091	1·0311
"	"	"	1904·0	1856·96	65·763	1·0353
					Mean	1·0329

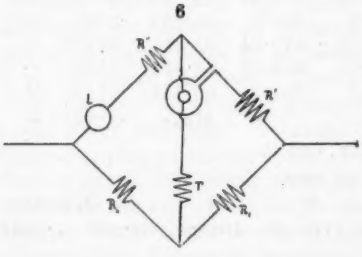
TABLE VI, Coil S.

May 13, 1904.

R_a	R′	r	R_l	R′	n	L	
100·16	99·42	1020·2	1816·9	1734·0	78·121	1·0345	henrys
"	"	"	"	1734·5	78·303	1·0359	"
"	"	"	"	1760·6	61·797	1·0307	"
"	"	"	"	1734·5	78·278	1·0325	"
"	"	"	1905·3	1819·3	81·410	1·0330	"
"	"	"	"	1818·3	81·700	1·0365	"
"	"	"	"	1848·8	62·604	1·0354	"
"	"	"	1616·0	1529·6	76·456	1·0333	"
"	"	"	"	1528·3	76·068	1·0294	"
"	"	"	"	1530·1	76·428	1·0299	"
					Mean	1·02331	"

III.

Method 13.—Method 13 was next tried. This is also an absolute method for measuring either self-inductance or capacity. It is a zero deflection method depending on a ninety degree phase difference just as in method 14. In fact it differs from that method only in that the fixed coils of the electrodynamometer are no longer in the battery arm of the bridge. The connections are shown in the diagram. Neglecting the self-inductance of the fixed and hanging coils of the electrodynamometer, the formula for the method may be deduced as follows. Proceeding as before, we find the ratio of the current in the fixed and hanging coils



$$\frac{C_2}{C_1}\epsilon^{i(\phi_2-\phi_1)} = \frac{r(R_a+R_l)+R_l(R_a+R''+ipL)}{R'R_a-R_lR''-ipR_lL}$$

Rationalizing the fraction, and taking the real parts, we have for zero deflection;

$$p^2L^2 = \frac{\{R'R_a-R_lR''\}\ \{r(R_l+R_a)+R_l(R_a+R'')\}}{R_l^2}$$

We should expect this method not to be as sensitive as Method 14, for the reason that we must in general have a smaller current in the fixed coils of the dynamometer. Moreover, since the formula is similar in character to that of Method 14, we would

look for the value of L to be affected in the same way by a slight heating of one or more of the resistances. The formula for Method 14, neglecting hanging coil correction is

$$p^2L^2=\frac{[R_1R''-R'R_2]\,[r(R'+R_1+R_2+R'')+(R'+R_1)(R''+R_2)]}{R(r+R''+R)}$$

The method was set up and some determinations made of the inductance of coil C. The method proved much less sensitive than Method 14, under comparable conditions only about one-half. By sensitive is meant the degree of accuracy to which it is possible to change the resistances, in securing adjustment.

It is to be noted that the formula as given neglects the self-inductance of the fixed and hanging coils of the electrodynamometer. The exact formula is not difficult to work out, but the method is hardly sensitive enough to justify the trouble.

A few measurements of the inductance of coil C were made with some care. The values obtained were low compared with those previously obtained, as will be seen from the following example.

$R_2=1201{\cdot}7$ ohms $\quad R''=1560{\cdot}6$ ohms $\quad r=309{\cdot}91$ ohms
$R_1=\ 99{\cdot}89$ " $\quad R'=\ 133{\cdot}33$ " $\quad n=\ 69{\cdot}153$ "
$L=1{\cdot}1483$ henrys

IV.

Methods 1, 2, 3, etc.—Attention was not turned to the first six methods given in Professor Rowland's paper, which are for the comparison of self-inductance with capacity. They are all zero deflection methods depending on a ninety degree phase difference. As will be seen from the formulæ, the value of $\frac{L}{C}$ is independent of the frequency. Two of these methods have already been used. Method 6 was studied by Mr. Penniman but did not yield favorable results. Method 3 was employed by Mr. Potts in the course of some work on electric absorption, and was found very satisfactory. The diagrams and formulæ for the methods are as follows. The method of deducing the formulæ is the same as that followed in the preceding cases.

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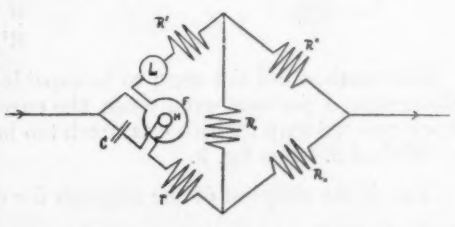

Method 1.—See fig. 7.

$$\frac{L}{C} = \frac{[r(R_1+R'')+R_4(r+R_1)]\,[R'(R_1+R_4)+R''(R_1+R')]}{(R_1+R''+R_4)^2}$$

The trouble with this method was its lack of sensibility. Various values of resistances and coils were tried, but with the arrangement, which was as sensitive as possible, the resistances could not be adjusted closer than 1/5 per cent. This also when the maximum current was flowing through the network. It will be noted that the formula is quite similar to that of Method 14, so we should expect the value of $\frac{L}{C}$ to be affected in the same way as was L by a slight change in one or more of the resistances. The values of the resistances which seemed to give the most sensitive arrangement when coil P was compared with a $\frac{1}{3}$-microfarad mica condenser were,

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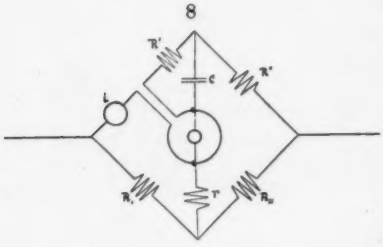

$R' = 336$ ohms $\qquad R'' = 100$ ohms $= R$

$R_1 = 1200$ ohms $\qquad r = 3900$ ohms

Method 2.—See fig. 8. When $L = \cdot 570$ and $C = \frac{1}{3}$-microfarad. The values of the resistances which seemed to give the most sensitive arrangement were,

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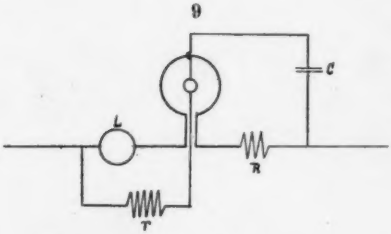


$R'' = R_4 = 100$ ohms

$R_1 = 1600$ ohms

$R' =$ about 1600 ohms

This method did not seem to be capable of adjustment much closer than 1 per cent even when the current through the network was ·08 amp., which was much too large to avoid heating.

Method 3.—See fig. 9.

This is the simplest of the methods for determining $\frac{L}{C}$. The formula is

$$\frac{L}{C} = rR'.$$

As has already been stated, this method has been used with

success. The present writers set up the method and compared coil P with the $\frac{1}{8}$-microfarad condenser. The method is very sensitive. With $r = 3070$ ohms and $R = 485$ ohms, a change of two ohms in r caused a change of 1^{mm} in the deflection of the electrodynamometer. Determinations of the ratio $\frac{L}{C}$ were not made for the reason that if we wish accurate results it is necessary to measure the absorption resistance of the condenser. This should be done at each determination of $\frac{L}{C}$, as the absorption has been found to vary greatly both with the temperature and the frequency.

The diagrams and formulæ for Methods 4 and 5 are given: also the values of the resistances of the arms which seemed to give the most sensitive arrangement. As before, coil P, was compared with the $\frac{1}{8}$-microfarad condenser.

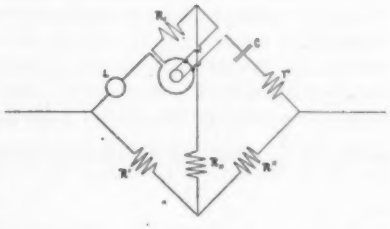
Method 4.—See fig. 10.

$$\frac{L}{C} = \frac{\{R'(r+R_a)+R''(R'+R_a)\}\ \{R'(R''+R_a)+R''(R_l+R')\}}{R'R''}$$

As adjusted,

$R_a = 88{\cdot}54$ ohms
$R' = 1021{\cdot}8$ ohms
$R'' = 99{\cdot}5$ "
$r = 492{\cdot}0$ "
$R_l = 317{\cdot}5$ "

10



With $C = {\cdot}086$ ampere, a change of 4·4 ohms in r is barely detectable and a change of ten ohms in R' produces only 2^{mm} deflection as measured on the scale of the electrodynamometer.

Method 5.—See fig. 11.

$$\frac{L}{C} = \frac{[R_l(R''+R_a)+R_a(R''+R')]\,[R'(R''+R_a)+r(R'+R'')]}{(R'+R'')\,(R''+R_a)}$$

As adjusted,

$R_a = 100$ ohms
$R'' = 88{\cdot}5$ "
$R_l = 1041{\cdot}5$ "
$R_l = 317{\cdot}5$ "
$r = 1678{\cdot}4$ "

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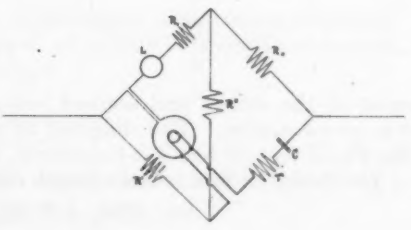

This method is somewhat more sensitive than Method 4, however, it is not possible to adjust closer than one part in five hundred.

V.

Methods 7, 8, 9, 10, 11, and 12.

Of the remaining zero-deflection methods which depend on a ninety degree phase difference, little needs to be said. Methods 7 and 8 are for determining $\frac{L}{C}$ but involve mutual inductance and are intended to be used with doubly wound coils. For accuracy greater than one per cent such coils are very undesirable on account of the electrostatic capacity, and should not be used. Methods 9 and 10 are for comparing mutual inductance with capacity. Method 12 was investigated by Mr. Penniman.

VI.

Methods 15–24.

The rest of the methods require at least two adjustments; first, the Wheatstone bridge must be balanced with direct currents, then adjustment made with alternating current so that the current through the bridge arm is zero. Of these methods, 15 and 16 are for comparing two inductances, two capacities or inductance with capacity. However, Method 15 requires after balancing the bridge with direct currents two simultaneous adjustments with alternating current; and Method 16 requires many resistances of known ratio. Method 17 is for the measurement of $\frac{L}{M}$, but as Professor Rowland points out: "It is difficult to apply, as two resistances must be adjusted and the adjustment will only hold while the current period remains constant." These methods did not seem to be worthy of trial.

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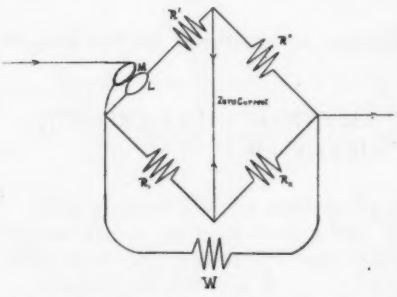

Method 18 is for the determination of $\frac{L}{M}$ where L and M belong to the same coil. This method is simpler than most of the others and seemed rather more promising, so it was given a trial. The diagram of the method is shown in fig. 12.

The bridge is first balanced with direct currents giving

$$R'R_2 = R'R'.$$

Then with alternating current W is adjusted until there is zero current through the bridge arm, as shown by an electrodynamometer or telephone. When this is the case the mutual inductance completely counterbalances the self-inductance, so that the currents and electromotive forces are in phase in each arm of the bridge. Representing current through R′ by I′, etc.,

$$R_1 I_1 = R'I' + ipLI' - ipM\,(I' + I_1 + I_w)$$

also
$$R_1 I_1 = R'I'$$

and
$$\frac{I'}{I_w} = \frac{W}{R' + R''}$$

$$\therefore \quad \frac{pM\,(I' + I_1 + I_w)}{I'} = pL$$

Hence
$$\frac{L}{M} = 1 + \frac{R'}{R_1} + \frac{R' + R''}{W}$$

The method was set up so that by means of switches the resistance W could be replaced by the battery, and the electrodynamometer by the galvanometer. The method proved very unsatisfactory. Using the electrodynamometer in the bridge arm, its coils being connected in series, W could not be adjusted closer than three per cent. Different values of the resistance were tried but the result was about the same. The electrodynamometer was then replaced by a telephone. It was then possible to adjust to about two per cent but the noise of the dynamo interfered somewhat with the use of the telephone. The conclusion was that the method is not sufficiently sensitive to be of value.

Method 19 is also intended for the measurement of $\frac{L}{M}$ but involves the use of a doubly wound coil.

Methods 20 and 21 require a specially doubly wound inductance coil. They were not thought sufficiently promising to merit the construction of such a coil.

Method 22 is Carey Foster's method adapted to alternating currents. This method was rather thoroughly investigated by Heydweiller.*

Method 23 requires two simultaneous adjustments with alternating currents, and Method 24 is only of special use in comparing two doubly wound coils.

Summary.

With the exception of Methods 14, 3 and 25 the Rowland methods tested are of little value, their chief defect being a

* Wied. Ann., liii, p. 499, 1894.

lack of sensibility. Method 14, or more properly, the Oberdeck method, is without doubt the best method that we have for the absolute measurement of self-inductance in terms of resistance. It is easy to apply and if proper care be exercised results should not differ from the mean by more than 2/10 per cent. Greater accuracy than this is undoubtedly attainable and ought not to be a matter of any great difficulty, for in the work here described the frequency determination could have been improved and the resistances much more accurately measured. Method 25 is better than the Rayleigh method as ordinarily used, is very easy to work and has a very simple formula, involving little calculation. Its accuracy is probably limited to about one per cent. Method 3 for comparing self-inductance with capacity is very sensitive and was found by Dr. Potts to be very satisfactory.

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Art. X. — *Climatic Features in the Land Surface;* by Albrecht Penck.

The surface of the land is composed of slopes which are for the most part gentle. Steep cliffs and overhanging forms are exceptional and insignificant features; where they occur, they are soon destroyed. Their fragments fall and slide and finally creep down; thus all cliffs and overhanging forms are transformed in the course of time into slopes and finally into long grades. It is important to see that this process can be accomplished simply by the force of gravity, helped by the action of weathering, but without the interference of water. The grading of the land surface is therefore a planetary process which will occur on every planet whose surface is liable to weathering as a result of changes of the surface temperature. The slopes formed by weathering are normal to the direction of those cliffs from which they originated, and if there was no stream or wave action, no glacial or wind action on the earth, the direction of slopes would be determined chiefly by the direction of the cliffs formed by earth movements, and we should observe in all slopes of the surface of the earth the directions of crustal and volcanic movements.

But the direction of the slopes on the land surface reveal other features, and a study of the processes going on on the land surface shows us that the origin of its slopes is above all connected with atmospheric action. Running water produces long and extensive slopes by its erosive and constructive force; it is enabled to transform slopes caused by crustal movements into others which show a perfect adjustment to the material of the earth's crust; and finally it wears the land down to gently sloping surfaces of the highest resistance. Running water also deposits material in the form of gently sloping plains, which extend very far. The action of running water is therefore both a degrading and an aggrading one, and the grades which it forms show a systematic arrangement; they slope down in the direction in which the water moves, mostly towards the sea; on one quarter of the land surface, however, towards the interior of the continent, where the running water is evaporated; and exceptionally in several regions composed of soluble rocks, to those points where water enters the rock to follow there a subterranean course. The latter case is a rather unusual one; it is connected with the very remarkable forms of the Karst phenomenon, which, however, are only of limited extent.

Glacial action also produces slopes, either due to erosion or to accumulation, but these slopes do not show such a systematic

arrangement as the grades of fluviatile origin. Glacial action does not impose on the land the continuity of its surface slopes as running water does; it produces irregularities in its bed which not only show continuous slopes but often opposite and reversed slopes. Wind also produces slopes, but their arrangement is still more irregular than those of a glacier bed. There is a sharp limit between the regions of glacial erosion and of glacial deposition; the forms of eolian erosion and eolian deposition also occur in close proximity; wind does not transport so continually nor so far as running water and glaciers do; its action is more brief and unsteady. Thus, the arrangement of the slopes of the land surface permits us to recognize fluviatile, glacial and eolian forms.

Now the action of running water and of glaciers and the display of eolian forces depend on climate; rivers exist only where a part of the rain runs off superficially on the land; their morphological action depends, therefore, on the amount of run-off, which is consequently a geomorphological factor of great importance. Glaciers are formed only where the amount of snowy precipitation surpasses that amount which can be melted away by the action of the sun. Wind action finally becomes very visible, and is exclusively performed where neither water nor ice action occur. We see, therefore, that the differences between precipitation and evaporation on one side and between snowfall and ablation on the other, determine the surface features of the land, and hence we can recognize in the surface features of the land certain features of its climate in the same way as in its covering with vegetation.

The display of river action does not depend alone on climatic conditions. River movement is only possible where there is a slope on which the rivers can flow. Only their existence is due to climate, while the display of their force depends on differences of elevation, and their action consists in the degradation of existing heights. Glaciers do not necessarily presuppose elevations; they can be formed also on low grounds, if the climatic conditions of their formation are given. If more snow falls on a plain than can be melted away, it accumulates and will finally form an ice-cap which radiates from the plain; if here the accumulation reaches a great thickness, it can then overcome finally by its surface slope existing inequalities of its bed, as is clearly shown by the glaciation of North America during the Great Ice Age, which partly radiated from the low grounds west of Hudson Bay and overflowed in the east the mountains of New England. Whilst river action consists in the destruction of given inequalities of the earth's surface, glacier action can create new inequalities by the erosion of the central floor of an ice-cap formed at a low level and the deposi-

tion of the eroded material in higher levels around this center. The same can be said of eolian action. Wind can blow sand and dust from lower levels to higher ones, and if its action were long continued, it could lower the surface of vast tracts of land and raise the surface of others; the lowered surfaces could lie below the raised ones.

In order to understand more thoroughly the difference of river action on the one hand and of glacial and wind action on the other, let us consider their probable final results. In the course of time the rivers will totally degrade the continents to vast peneplains and will extend them seaward by the accumulation of river plains; then they will have no action. A polar ice-cap will attack its floor if the slope of its surface is greater than the reversed slopes of its floor, and around this eroded area accumulation will go on. The difference of height between the central eroded area and the peripheral belt of deposition will be theoretically the larger the greater the thickness of the ice-cap, and it is theoretically possible that a very thick and moving polar ice-cap could finally excavate a deep basin in the polar region which would be surrounded by a high morainic belt. These processes would not only be accomplished on the land, but the ice-cap could also act on those parts of the sea-bottom which are not deep enough to make the ice float; and the morainic belt could therefore be accumulated as well on the land as on the bottom of the sea. But where the bottom of the sea becomes too deep, the ice-cap would break into pieces which would float away as icebergs and distribute the morainic material over vast areas of the sea-bottom. Let us assume that wind action operates unhindered by vegetation and the action of running water. Then the constant trade-winds would continually carry with them sand and dust which were accumulated in an equatorial belt, where the trade winds cease, and this action would be continued as long as the area eroded by the wind were not invaded by the sea. It could be eroded beneath sea-level as long as there were coast regions protecting it as natural levees against the waters of the ocean. Wind action does not necessarily stop at sea-level; the depressed areas of the land clearly show us that it is continued farther down. If, however, those natural levees are destroyed, vast regions denuded by wind action below the sea-level would suddenly be inundated and converted into seas. The material transported by the wind would be deposited not only on the land, but also in the neighboring seas, and an increase of the equatorial land area would be the consequence of continued wind action. Thus, by mere eolian activity, the distribution of water and land could be altered.

The effects of polar ice-caps and continual wind action would

consist in the movement of material from higher latitudes into lower ones, and the areas of erosion and deposition would show a zonal arrangement, whilst running water transports from higher regions to lower ones, and the corresponding areas of its action are controlled by the existing distribution of water and land. Glaciers and winds accomplish an important transportation of material from lower to higher positions. What we see in river action consists only of a downward transportation, and it generally ceases at sea-level; it can only be exercised below it in countries which extend for other reasons below this level, as for example, in the border regions north of the Caspian sea; whilst glaciers and winds could make vast depressions of the land beneath the sea-level.

These differences between visible river action on the one hand and glacial action on the other seem to be at first sight very strange, but a closer inspection shows that when speaking of river action we generally have in mind the processes which go on above the level of the river. We generally do not think of the processes performed in the river bed itself, for they are hidden under the water. But the study of river beds reveals that here much material is carried upwards and that the depth of the rivers is not at all limited by the sea-level. All river beds which reach the sea lie below the level of the sea near their mouths, and their bottoms extend the deeper and the farther below the sea-level the greater their volume. On the other hand, if we speak of glacial or wind action we have always in mind the processes going on in the beds of these moving fluids. These beds are of far larger extent than those of rivers, and therefore the action performed in them is far more conspicuous. The action of rivers in their beds gives origin to all those subærial processes which widen the vertical trench of a river into a valley and produce slopes towards the river. These subærial processes are the more important for the development of the earth's surface-features; they perform what we usually call river action, but they are not controlled by the movement of water, and belong to that class of phenomena which are dependent on the action of gravity.

The actual surface features of the land differ from those which are produced by continuous river, glacial and wind action. The land is not leveled down to a peneplain, no mountainous moraines are formed around vast depressions, and there is no equatorial belt of wind deposition between regions where deflation produced lowlands. We meet with elevations which are still in the state of being degraded and which are not made by glacial or eolian accumulation. The existence of those elevations reveals the existence of forces which counteract the atmospheric agencies, and which have

counteracted them the more, the greater the difference between the actual distribution of heights and the ideal ultimate effect of those agencies. In countries with dominant river action the existing elevations are differences between the effects of earth movements and the consequent degradation by river action. Their height is therefore determined by the intensity of crustal movement and by the time that has since elapsed. There are young mountains, attacked only along certain lines by water, which has only made an approach toward destroying the fortress; there are mature mountains which have already lost their unstable annexes and are formed by rocks of greatest resistance; there are old mountains degraded as far as possible, no longer forming elevations.

Young, mature and old mountains show very different structures, and we cannot, therefore, connect the idea of a certain class of crustal movement with mountain-making. Mountains are caused by all crustal and volcanic movements which are directed upward, either totally or as a component. But whatever the character of these movements is and however complicated they may be, they only exceptionally interrupt the slopes of fluviatile degradation. This is shown by the facts that even in the regions of most recent elevations the continuity of the fluviatile slopes or grades is only exceptionally interrupted, and nearly all of these interruptions occur in volcanic regions, where sudden outbursts take place. The intensity of crustal movement, therefore, is not so great that it can disturb the continuity of fluviatile slopes; crustal movement can disturb a former arrangement of slopes, it can produce new slopes, but by their erosion and accumulation rivers maintain the continuity of slopes.

In desert regions crustal movements are able to interrupt slopes, for they are not counteracted by running water. It is in the deserts of the Far West where we see the best samples of recent faults; they cut through alluvial fans and form well-marked steps in regions of deposition and erosion. It is also in the deserts where we meet with such an arrangement of mountains that closed basins are formed. These closed basins came into existence because the grading river action was absent, and though formed by crustal movement, they are also climatic features of the earth's surface, for they are only produced under certain climatic conditions, namely, in regions where the amount of evaporation surpasses that of precipitation.

We see on the earth's surface not only the features of the present climate but also those of a past climate. Very extended areas, formerly covered by ice, are now exposed to river action. The basins formed by the meeting of normal slopes and those reversed slopes which originated under the ice, are filled with

water and form lakes; the river action has not reached a normal slope; waterfalls interrupt their courses. These lakes and waterfalls are indications of extreme youth of river action over large areas, and at the same time they are as significant morphological evidences of a recent climatic change as moraines and rock striations are in the geological sense. In mountain regions, as for example in the Alps, the lakes occupy valleys which have the arrangement of river valleys; they are subordinate to an older topography, formed by fluvial action, and we can recognize in the valleys of the Alps not only one climatic change, but a succession of those changes. In the lowlands of the north, however, it is nearly impossible to trace the features of an older topography under the glacial one. This, however, does not show those signs of antiquity which we might expect to find in regions of continual glaciation. Hence we must infer that the glacial features of other northern lowlands are also superposed on an older topography which has been destroyed in its characteristic features. We see on the border regions of the old glaciations moraines which have totally lost their morainic forms, and already possess the surface features of a mature fluviatile topography. These surface features have long ago led to the conclusion that we have to deal here with older moraines, which indicate an older climatic change. Thus regions of river degradation indicate climatic change by their composition as well as glaciated regions indicate such change by their forms.

We meet with proofs of climatic changes also in desert regions. Investigations of American geologists, especially of Gilbert and Russell, have shown that the region of Great Salt Lake was once occupied by a far larger freshwater lake, the shore lines of which can be easily followed and the outlet of which can be recognized in a side valley of Snake river. We can trace in the Sahara very extended river valleys from the Highland of Ahaggar down to the region of the south Algerian Shotts. These valleys cannot be compared with those short wadies in which the water of cloudbursts rushes down. They indicate a former moister climate; the desert with its surface features extends here over a region of former water action in the same way as, farther north, river action is now displayed on a surface formerly covered by glaciers.

In the interior of two continents we finally meet with surface features which might be taken for morphological indications of a change of desert climate into a moister one. Three large lake basins interrupt the general grades of the head waters of the principal African rivers. In the region of the Zambesi river we find the very deep Lake Nyanza, in the catchment basin of the Congo the likewise deep lake Tanganyika, and

along the upper branches of the Nile the Victoria Nyanza. There are good evidences that the two first named lakes occupy depressions formed by crustal movement. Now we have seen that generally crustal movements, however profound they may be, do not interrupt the formation of slopes of degradation. Why did such interruption occur in central Africa? In order to give an answer, let us consider how the formation of isolated basins by crustal movement is hindered in the regions of fluviatile drainage. A tract of land, sinking down, is filled up by sediment during its subsidence; thus the rivers maintain their slopes and the formation of closed basins is counteracted. Elevations occurring in river basins are often cut through by rivers during their elevation, and then they will not transform neighboring regions into closed basins. The formation of those basins by crustal movement will occur only when the rivers in the disturbed regions are too feeble to fill up the sinking regions and to cut through the rising chasms. The central African great lakes are located in the neighborhood of insignificant river action. East of them extend the dry plateaus of German East Africa. Here crustal movement has produced many closed basins called Gräben (tectonic troughs) by Suess. Many of these Gräben are empty, or filled only at their bottoms with soda-lakes; others are nearly filled, as for example, Lake Rudolph. A slight climatic change would fill the basin of this lake so that its waters would overflow in wet years. This is the case with Lake Tanganyika. Its outlet, the Lukuga, flows only in wet years; in dry years the great lake is without outlet. A stronger climatic change would transform Lake Rudolph into a normal freshwater lake with permanent outflow. This type of lake is represented in the neighborhood by the Victoria Nyanza, by the Albert and Albert Edward Nyanza, and farther south by Lake Nyassa. We can understand best the existence of the large freshwater lakes of east equatorial Africa by assuming that their water drowns basins formed in a dry climate, such as prevails farther east. It is very significant that these great lakes occur in a region of transition between the dry and the wet tropical climate, a region which would be affected very much by climatic changes. The same is true for Lake Baikal in eastern Siberia. It belongs to a zone of great inland lakes at the northern border region of the central Asiatic deserts. Three of these lakes have salt water; two of them are so large that they are called erroneously seas, namely Lake Caspian and Lake Aral; the third is the shallow lake Balkash. An increase of precipitation over Russia would cause a raising of the level of Lake Caspian and an extension of its surface, and if on this larger surface evaporation would not balance the increased

inflow, and establish thus a new equilibrium, then the lake will overflow in the Manich valley and would be changed in the course of time into a freshwater lake. On the other hand, if the desert region of Mongolia should extend, the principal affluent of Lake Baikal would become smaller, and a moment would arrive when the quantity of water running into Lake Baikal would be totally balanced by the evaporation going on there. Then this lake would lose its outlet, and the salts brought by its affluent would gather in its basin, and it would be transformed into a salt lake. Such rather light climatic changes would transform the salt lakes of the northern border regions of the central Asiatic deserts into freshwater lakes, or the large freshwater lake into a salt lake. We can understand best the existence of these lakes by the working hypothesis that their basins were formed originally in a dry climate, where river action could not neutralize transformation by crustal movement, and that they thence were more or less filled with water, according to the actual climate of their region. In this way we are disposed to recognize also in the great freshwater lakes in the interior of some continents morphological witnesses of climatic changes.

If we now look over the whole set of evidence, we see morphological traces of glacial action in countries which are now drained and shaped by running water, and recognize in mountain chains, as for example the Alps, traces of river action preceding this glacial action. We follow traces of extended river action into the desert, and we find forms which were probably produced in a dry climate, with no run-off, in regions which are now subject to river action. The climatic features of the land surface indicate that climatic changes are not only in one direction; we cannot say that the climate of the land is becoming dryer and dryer, or less and less glacial; they reveal continued climatic oscillations. These climatic oscillations are different in the different zones of the earth. We have to deal with oscillations between glacial and pluvial climate, and with oscillations between pluvial and desert climate. It is now the question, how these different oscillations were connected with one another, if there is a contemporaneity between them; and which changes were contemporaneous, those of glacial to pluvial climate with those of pluvial to desert climate, or *vice versa*. The evaporation of the deserts of the Far West has given one answer: it was there shown that the glaciers existed at the same time that the climate was moister. From this we can infer that one of the climatic oscillations indicated by the surface features of the earth consisted in a movement of the climatic zones from the pole towards the equator and back again. If this inference is right, we must find on the equatorial belt of

the great desert regions of the world traces of an old desert climate, where now a pluvial climate dominates. It is possible that the great central African lakes point in this direction; perhaps Lake Titicaca indicates by its content of rather fresh water that once the deserts of South America extended farther towards the equator, and perhaps the lakes of the plateau of Mexico point to the same relation with the deserts of North America, whilst Lake Baikal would indicate an opposite movement of the climatic zones from the equator towards the poles, which cannot have been contemporaneous.

There is one fact known from the Arctic regions which is in harmony with a migration of the climatic zones of the earth. Neither the American expeditions which have explored the neighborhood of Smith Sound, nor the Norwegian expedition which studied the archipelago lying farther west, succeeded in finding the traces of a former greater extent of the glaciers, which are so abundant farther south. At first sight this fact appears rather strange, but it can be understood in connection with the others. It shows that during the glacial period glacial conditions did not extend farther towards the pole into those regions where now the Arctic climate, on account of its dryness, is not very favorable to the formation of glaciers. The great glaciations of the northern hemisphere were not extensions of a polar ice-cap; they were confined to the vicinity of the Arctic circle, and they surrounded, as far as we can see, a region of an Arctic desert climate similar to the existing one. This fact would be consistent with an equatorial movement of the climatic zones of the earth.

If there are oscillations in the situation of the climatic belts of the earth, it must be asked if they are connected with the disappearance of existing climatic zones and the appearance of new ones. For this reason the equatorial and polar regions attract particular interest; it can be imagined that in times of an equatorial movement of the climatic belts some features of the equatorial climate would totally disappear, and new climatic conditions could come into existence in the polar regions. The reverse would occur in times of a polar movement of the climatic zones. There is also much interest in the study of all border regions of climatic belts, for every movement of climatic zones of the earth would here produce changes.

The very extended border region of the glacial and the pluvial climate has afforded a splendid occasion for the study of past climatic changes; the climatic history of the great Ice Age could here be determined by a careful study of the corresponding deposits, and newer researches have utilized to great advantage the glacial forms in determining the glacial climate. The forms of the earth's surface indicate climatic changes also

in other regions of the earth, and further research will help us to establish the general rule of all their climatic oscillations, and we shall understand them the better the greater our knowledge of the surface forms.

The forms of the earth's surface are very complex things. In the beginning of geological research it was generally maintained that every rock had its peculiar forms, and still to-day some text-books contain pictures of granite or sandstone mountains. Later, it was believed that every kind of structure of the earth's crust assumed its own surface features, and structural geology was regarded as the very content of geomorphology. Later still was recognized the importance of the different exterior processes which shape the earth's surface, and there are still many differences of opinion as to their effects. It is only recently that the full importance of time has been observed for the development of surface features. After having seen how different the forms are which come into existence in a natural sequence under the control of a certain process, as shown by the geographical cycle, we can fully appreciate the differences of fluviatile, glacial and desert forms, and we shall have thus gained the possibility of such a close examination of forms that we can read their history.

This study of erosional forms can be supplemented by that of corresponding deposits. We now easily separate river deposits from moraines, which in the beginning of scientific research have been taken for the results of large floods. It is also possible now to distinguish the deposits of different phases of a geographical cycle from one another, and the variegated or impoverished composition of gravel deposits allows conclusions as to the surface features which prevailed during their formation. We do not doubt that continued observations of desert deposits will result in the establishment of sharp distinctions between them and fluviatile deposits, though it is not easy to distinguish between deposits of young rivers of a pluvial climate and those of mature rivers of a desert climate. Thus the study of deposits may afford us a crucial test as to the result of our study of forms.

Forms are always in the way of evolution; where destruction prevails on the land surface the existing forms are always in process of destruction; only where they are buried under new deposits are they conserved. The surface of every layer deposited on the land has been an old land surface. Thus the study of deposits also reveal forms of the past, and if we are accustomed to interpret the meaning of forms and deposits, we can read far older climatic conditions in deposits than are exhibited in the existing surface features of the land.

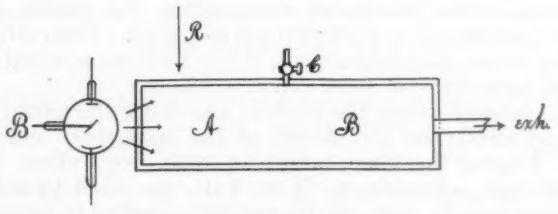
ART. XI.—*Preliminary Results with an Objective Method of Showing Distribution of Nuclei Produced by the X-rays, for Instance;* by C. BARUS.

[The present research was carried out experimentally by Robinson Pierce, Jr., and myself, and I would gladly associate his name with mine at the head of this article, did he permit it.]

1. *Introductory.*—By passing the X-rays into one end of a long rectangular (virtually tubular) condensation chamber and observing the effect produced after successive different intervals of time by the condensation method, evidence with a possible bearing on the origin of these nuclei was obtained. The coronas are distorted and at first occur on the bulb side of the apparatus only. The distribution of nuclei is inferred from the form of the corona.

The experiments described were all made with *strictly dust-free* saturated moist air, as both the method of precipitation

1



and of filtration were applied prior to each experiment, and the exhaustion carried to a higher degree in the purifications than in the measurement. Furthermore as the exhaustions necessitated the use of short lengths of rubber tubing (1/2, 3/4, and 1 inch in bore in the different cases), the amount of cooling obtained does not directly correspond with the pressure difference, δp, owing to the resistance of the tube to the flow of air. The data, δp, each refer to a given type of apparatus but are satisfactory as relations, so long as this is not changed. Furthermore the δp was so adjusted as to entrap all X-ray nuclei, to the exclusion of the normal, quasi-molecular nuclei of dust-free air.

2. *Apparatus.* — The method was purposely reduced to extreme simplicity and the apparatus is shown in the annexed diagram. AB is the long rectangular condensation chamber of wood impregnated with resinous cement. The front and rear faces are plate glass through which the coronas may be observed. The other sides are lined within with thick cotton cloth, kept wet, and there is a layer of water at the bottom to

insure complete saturation of air. C is a stopcock leading to an efficient filter (not shown). Supersaturation is produced by sudden exhaustion at the B-end of the apparatus, while the A-end receives the radiation from the X-ray bulb B'. A large vacuum chamber was placed in connection with the exhaust pipe shown, through a wide stopcock, the details of which need not be explained. The X-rays used were not very penetrating, and were obtained from a soft bulb actuated by a small induction coil (4″ spark) and 3–5 storage cells. Two filters of solidly packed cotton were used, one 7 inches and the other 16 inches long. They were about equally efficient.

3. *Vertical radiation at one end of the trough, entering through wood.*—In the preliminary experiments the bulb was placed so as to radiate into the trough in the position shown at R, and kept in action 5 min. The effect was then observed by condensation at the pressure difference $\delta p = 17^{cm}$. Two results were noted: in the first place while the coronas obtained with the X-rays in bulky apparatus are usually of the smaller or normal type, the coronas seen in this shallow apparatus were often enormous, transcending the middle g–b–p corona (nucleation, $n = 100{,}000$ per cub. cm.). Even after two or three subsequent exhaustions, filtered air being added prior to each, large coronas were still in evidence.

In the second place, the coronas, and hence the nuclei, were observed chiefly on the A-side of the apparatus, under the bulb. Fearing that there might be some direct effect due to induced high potentials, the X-ray bulb was raised 10 and 20^{cm} above the trough, with results naturally smaller in magnitude but of the same kind. The following data may be given:

TABLE 1.—Number of nuclei, n, in thousands per cm^3. $\delta p = 17^{cm}$. Temp. about 20°; angular aperture $\phi = s/30$.

	Bulb near trough (2^{cm})						Bulb 10^{cm} above trough				Bulb 20^{cm} above trough	
Time of radiation ----------	5 min.		5min.		5 min.		6 min.		5 min.		6 min.	
	s	n	s	n	s	n	s	n	s	n	s	n
Coronas on 1st exhaustion	*	—	*	—	*	—	3·9	20·5	3·5	15	2·7	6·6
" " 2d "	5·9	6·8	—	—	6·5	100	2·7	6·6	2·7	6·6	1·9	2·2
" " 3d "	—	—	—	—	5·9	68	—	—	—	—	—	—

* Immense but too diffuse for measurement.

In all cases the first coronas were accompanied by dense rain and fogs frequently in horizontal strata, so that sharp measurements of aperture are generally out of the question. Moreover the first condensation is accompanied by turbulent displacement of fog-particles, and the contents of the receiver are thoroughly stirred up. After filling with filtered air and

exhausting again, the coronas are therefore nearly uniform and alike on both sides. In the above table the nucleation produced decreases about as the inverse square of distance.

4. *Axial radiation entering one end of trough.*—Seeing that it is possible to retain the nuclei on one side of the trough, subsequent experiments were conducted with the X-ray bulb placed as shown in the figure. Moreover a smaller interval of radiation was selected, to more and more fully exclude the displacement of nuclei by diffusion. The angular diameters ($s/30$) of the coronas were measured with two gonimeters, one on each side (A and B) of the trough, the distance of the coronal centers from the bulb being about 20^{cm} and 47^{cm}, respectively. The following table summarizes the results obtained, remembering that all initial coronas are coarse and blurred and accompanied by copious rain and fog, so that the diameters must be estimated.

TABLE 2.—Number of nuclei in thousands per cm^3. $\delta p = 17^{cm}$; angular diameter $\phi = s/30$.

Time of radiation	2·5 min.				3·5 min.				2 min.				2 min.			
	A-side		B-side		A-side		B-side		A-side		B-side		A-side		B-side	
	s	*n*	*s*	*n*	*s*	*n*	*s*	*n*	*s*	*n*	*s*	*n*	*s*	*n*	*s*	*n*
Corona on 1st exhaustion	4·5	32	2·2	3·3	4·5	32	2·2	3·3	4·0	22	2·0	2·5	2·5	5·2	0	0
" " 2d "	—	—	—	--	3·2	11	3·0	9·3	—	--	—	—	—	—	—	—

The second coronas are obtained after refilling with filtered air and it is noteworthy that after the rains of the foggy first coronas fall out (which they do rapidly), there are abundant nuclei left for the next corona. As stated, the nuclei are now uniformly distributed, and the coronas persistent, while in the first exhaustion, apparently, certain larger particles captured all the moisture and removed it in a rainy precipitate.

It is to be observed moreover that the nucleations on the A and the B sides in these cases are on the average as 9 : 1 or in a larger ratio, while the ratio of distances is below 1 : 2, because the absorption of the wood is equivalent to a removal of the bulb. Hence the density of distribution falls off faster than the inverse cube. The contrast is even greater, because in the 2 or 3 minutes of radiation some nucleation must arrive on the B-side by convection and diffusion.

We were originally of the opinion that there is marked absorption of the nucleating power of X-rays, by the successive vertical layers of air from left to right, but it is best not to prejudge the case here.

5. *Continued for larger pressure differences.*—Several questions now present themselves for immediate decision:

viz., whether all the X-ray nuclei have been caught and in how far the exhaustions are below the point of spontaneous condensation of moist air. Accordingly larger pressure differences were applied. Table 3 gives a few examples.

TABLE 3.—Nucleations n in thousands per cm^3. Time of exposure to X-rays, 3·5 min. Angular aperture $\phi = s/30$.

$\delta p =$	17^{cm}		21^{cm}		31^{cm}	
Side	A	B	A	B	A	B
$s =$	4·6	1·8	3·9	2·1	2·8	2.5
$10^{-3}n =$	35	1·9	27	3·5	11	7·8
Ratio	18 : 1		7·7 : 1		1·4 : 1	

Hence above $\delta p = 21^{cm}$ for this apparatus, nuclei show themselves on both sides and the question arises to what extent the normal air nuclei or ions have been captured. At $\delta p = 31^{cm}$, the fog particles condensed on X-ray nuclei probably drop out at once and the persistent corona observed is precipitated on the normal or inseparable air nuclei stated.

6. *Spontaneous condensation in moist air in the absence of X-ray nuclei.*—With the object of finding the pressure difference of exhaustion, δp, corresponding to the lower limit of spontaneous condensation of moist air without foreign nuclei, experiments were first tried with a cock 3/4 inch in bore, in the exhaustion tube. The results were identical on the A and the B sides, as follows:

TABLE 4.—Spontaneous condensation in saturated air. Angular aperture $\phi = s/30$.

	$\delta p =$	24^{cm}	31^{cm}
	$s =$	2·2	2·7
Repeated,	$s =$	2·4	3·2
"	$s =$	2·1	—
Do., large filter,	$s =$	2·2	3·5
Do.	$s =$	1·9	—
Air over nights,	$s =$	2·0	—
Mean	$s =$	2·1	3·1
	$n =$	3,500	15,500

$\delta p = 22^{cm}$, $n = 0$

This indicates that at a pressure difference of about $\delta p = 22^{cm}$ for the given apparatus and dust-free moist air, spontaneous condensation with vanishing coronas begins, and that thereafter the coronas increase regularly.

In corroboration with the preceding, similar experiments were tried with an instantaneous valve, opening with a hammer, and having a clear bore of over one inch. The results shown in table 5 were identical on both sides but unexpectedly

irregular. Alternation of large and small coronas in dust-free air, such as are here imperfectly shown, may be kept up indefinitely if strictly identical conditions are retained. Effectively, the large fog particles emit more nuclei, the smaller fewer nuclei for the next condensation in order, everything else remaining the same. The importance of these oscillations about the mean aperture, whether the emission is ionized or not, cannot be called in question, as I shall show elsewhere.

TABLE 5.—Spontaneous condensation of saturated air. Angular diameter $\phi = s/30$.

Press. diff., $\delta p =$		19^{cm}	$19{\cdot}4^{cm}$	$21{\cdot}4^{cm}$	24^{cm}
	$s =$	2·3	3·4	3·3	4·4
Repeated,	$s =$	0	2·1	2.0	2·5
"	$s =$	0	0	3·0	4·3
"	$s =$	0	0	2·0	3·5
"	$s =$	—	0	3·5	3·3
"	$s =$	—	—	2·2	3·3
Mean	$s =$	0	0	2·7	3·6
	$n =$	0	0	7,600	21,000

$\delta p < 20^{cm}$, $n = 0$

For $\delta p = 19{\cdot}4$ and below, therefore, no nuclei appeared after thorough cleaning. For $\delta p = 20^{cm}$ and above, i. e., at a somewhat lower pressure difference than before in consequence of more rapid exhaustion, spontaneous condensation begins. The large coronas are blurred.

Hence in neither case will spontaneous air nuclei be caught at $\delta p = 17^{cm}$, in the given apparatus.

7. *Possibility of producing nuclei by very sudden intense exhaustion.*—This condensation of moist air in the absence of foreign nuclei is usually considered due to the spontaneous ionization of the air, the available nuclei increasing in abundance, as with increasing pressure differences the sizes of captured nuclei are smaller, until the air molecule itself is approached. It follows then that the normal dust-free air always contains unstable systems.

Hence the question may well be asked, whether very sudden and intense exhaustion may not itself possibly be productive of nuclei. Thus if an unstable molecular configuration is just about to break down, it is conceivable that the tendency to break-down is accentuated by the violent treatment in question.

We made some experiments on this subject,* using a pres-

* Investigations on the spontaneous condensation in moist air were first suggested by C. Barus, in Bull. U. S. Weather Bureau, No. 12, 1893, pp. 11–14, 48. They have since been fully treated in the masterly work of C. T. R. Wilson, Trans. Royal Soc. Lond., vol. 189, pp. 265–307, 1897; ibid., vol. 192, pp. 403–453. 1899.

sure difference $\delta p > 30^{cm}$, by placing a gold leaf electrometer, properly insulated, in the condensation chamber. The loss of charge in damp air is at first surprisingly small; nevertheless the experiments are very difficult and we were unable to come to a conclusion. A decision will probably be reached by aid of the oscillating coronas mentioned in § 6.

8. *Successively increasing times of exposure to X-radiation.*—After this digression experiments were resumed with the apparatus as shown in the figure. The pressure difference $\delta p = 17^{cm}$ was used throughout, as this is well within the lower limit of spontaneous condensation for the given receiver, while coronas may be obtained with X-ray nuclei for pressure differences even lower than $\delta p = 10^{cm}$. Such coronas are vague, however, until the rain nuclei are thrown out, and on second exhaustion (n-39000, $s = 4{\cdot}8$ were usual values after 4 minutes ionization) they are naturally faint.

The immediate incentive to the work of the present section was given by the occurrence of elliptic distortions of coronas as shown in the following tables.

TABLE 6.—Distorted coronas. Increasing times of exposure to X-rays. $\delta p = 17^{cm}$. Coronal center 19^{cm} (A-side) and 46^{cm} (B-side) from bulb. Angular aperture $\phi = s/30$.

Time	2 min.	
Side	A	B
First exhaustion,	$s = 4{\cdot}5$, elliptic, strong	1·0 ? faint, circular
Second "	$s = 2{\cdot}7$, circular	2·4 circular
First "	$s = 4{\cdot}6$, elliptic, strong	0·0
" "	$s = 4{\cdot}6$, " "	0·0

TABLE 7.—Preceding table continued.

Time	1 min.		2 min.		3 min.	
Side	A	B	A	B	A	B
$s =$	3·1, round, strong	0	4·1, elliptic, strong	0	5·8, ellipse, larger and distorted	0

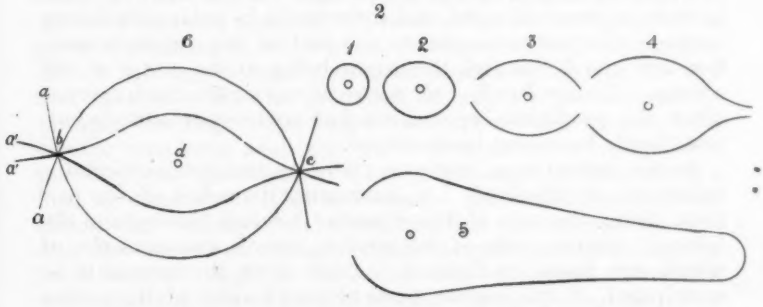
On second exhaustion, after refilling with filtered air, the coronas were nearly identical on both sides.

A series of observations was now systematically carried out, unfortunately with somewhat weaker radiation. After 1, 2, and 3 minutes of exposure, respectively, the coronas on the A-side were round to roundish (cf. figs. 1 and 2), of gradually increasing strength and density, and with rainy precipitation and fog usually marked. There was nothing on the B-side even after 6 minutes of exposure.

After 4 minutes (cf. fig. 3), the corona became spindle-shaped, $s = 5{\cdot}4^{cm}$ in major axis, accompanied by rain from horizontal layers of fog.

After 6 minutes of exposure to the X-rays, the coronas underwent remarkable distortion, becoming gourd-shaped (fig. 4), often with a long, serpentine neck, dipping into the B-side of the condensation chamber. The length of figure on the goniometer was about $6{\cdot}8^{cm}$, the outline being orange and the field within greenish. Rain and fog abounded. The coronas on second exhaustion (after adding filtered air) were g–b–p, $s = 4{\cdot}9$, $n = 42000$ and w–r–g, $s = 4{\cdot}5$, $n = 32000$, on the A and B sides respectively. The experiment was repeated with like results.

After 8 and 11 minutes of exposure, both the A- and B-side became the seat of the now wedge-shaped corona (cf. fig. 5),



greenish within and orange in outline. There was much rain and fog.

The figures, 1–5, are seen immediately after the exhaustion. A moment later there is a storm-like disturbance in the condensation chamber, accompanied by rain and fog. Hence the distribution of nuclei found on exhaustion is incompatible with a persistent distribution of fog particles. In fact the first coronas usually fall out rapidly, showing the occurrence chiefly of large fog particles in spite of the horizontal extent of the corona. The second coronas are circular and persistent, whence a nearly uniform distribution of nuclei may be inferred.

9. *Symmetrically graded sizes or numbers of fog particles.*—Since the coronas obtained all show an unmistakable tendency to horizontal symmetry with reference to the longitudinal axis of the condensation chamber, the nuclei to which the coronas are due must either originate in, or else be absorbed by, the top and bottom of the apparatus. Nuclei originating or lost at the front and rear faces are nearly uniformly distributed normal to the line of sight and produce circular coronas. Nuclei origi-

nating or lost at the left hand end of the chamber will additionally distort the corona, and such distortion is in evidence.

Mere inspection of the coronas, 1–5, shows that they are larger for fog particles near the axis, and smaller for particles near the top and bottom of the condensation chamber. Hence it is next necessary to explain that the details of the distorted coronas observed actually correspond with a gradation of the number of *effective* or available nuclei, from the axis outward on all sides. In the case of linearly graded fog particles increasing in diameter, δ, from bottom to top (h), it appears that the equation of the apertures, s, of the loci* of like color of the coronas is

$$s = -\frac{\delta_0}{a \sin \phi}\left(1 - \sqrt{1 + \frac{2 a s_0 \sin \phi}{\delta_0}}\right),$$

where s_0 is the aperture of the particles of diameter, δ_0 in the horizon or plane of sight, and ϕ the angle in polar coördinates between the radius vector to the part of the corona in question and the horizontal, the origin being at the center of the corona. Finally $\delta = \delta_0 - ah$, where $2h = s \sin \phi$. Such coronas when the gradation becomes marked are *campanulate* in outline, finally becoming basin-shaped.

In the present case, however, there are two symmetrical distributions of this kind, i. e., increasing diameters of fog particles from the axis of the chamber towards the top and the bottom. Hence pairs of intersecting curves, two examples of which are given in figure 6 ($a' > a$), show the coronas to be anticipated, if the remote parts beyond b and c of the corona are ignored, as they have no bearing on the symmetrical case, and only the curves surrounding the spot of light, d, admitted. In other words, as the distance bc, varying with the number of axial nuclei and the distribution constant a, increase, all the figures 1, 2, 3, 4, 5, may be logically evolved.

On the left end face, moreover, there would be special interference with the distribution of nuclei giving rise to the corresponding distortion seen in the coronas. Further distortion due to the decrease from left to right of the intensity of the radiation must also be apparent, and the gradient of distribution will be slightly altered by diffusion. One may note that if anything issues from the walls of the vessel, it comes as abundantly out of the water below as out of the wet cloth above.

10. *Origin of nuclei at the walls of the receiver.*—As has already been suggested, the observed gradation of fog particles may result from the (real or virtual) evolution of effective nuclei at the top and the bottom of the apparatus, in conse-

* Barus: this Journal (4), xiii, p. 309, 1902.

quence of the impact of X-rays on those parts, associated with secondary radiation. There is much electric evidence against such an explanation; nevertheless it is worth a brief examination.

The enormous coronas which have been obtained with the above (shallow) apparatus as compared with the small coronas seen in the cases of more bulky apparatus is in keeping with this view. Again, the rapid decrease of the nucleating power of the X-rays is to some extent referable to the increasing obliquity of the rays.

The observed distortion of coronas is clearly due to a gradation of nuclei, *either as to size, or number,* or both. If efficient nuclei issue from the top and bottom they must be present in greatest number near those parts of the apparatus, and consequently the largest diameter of coronas should apparently be found there. But if the largest number of effective nuclei is present near the top and bottom, the tendency to growth by cohesion will also be most marked in those regions. Hence the largest nuclei must be looked for nearest the top and bottom, while the gradation in size decreases regularly towards the axis. The large nuclei, therefore, may be sufficiently numerous near the walls to capture all the available moisture on condensation, leaving the small nuclei without a load of water and unable to descend. Hence the marked rain effect, the rapidity with which the first coronas usually drop out, the turbulent motion which succeeds condensation, the occurrence of large persistent coronas on second exhaustion even after the first coronas have quite dropped out, etc.

Finally one may note that secondary radiation issuing from the top and the bottom of the condensation chamber would accentuate the present effect.

Thus it seems not unreasonable to infer that nuclei are produced by the impinging X-rays in much the same way in which they are produced by high temperature (ignition), or by high potential; and the question arises whether the nuclei thus easily set free may not be associated with the electrons to which the cohesions between the molecules may be ascribed.

11. *Absorption of the ions at the walls of the receiver.*—If the nuclei due to the ionization of air by the X-rays are absorbed at the walls of the receiver* a diffusion gradient will be established, resulting in a decreasing number of nuclei from the axle outward, a distribution the reverse of the preceding. The observed distortion will, therefore, here be due to a gradation in the number of nuclei.

* A number of similar cases have been worked out in Smithsonian Contributions, No. 1309, 1901, "Experiments with ionized air;" and ibid., No. 1373, chapter v, 1903.

The difficulty in the present instance, however, seems to be fatal; for no reason is suggested why the coronas on second or third exhaustion do not eventually show flowerlike distortion, which they never do. In other words, it is here tacitly assumed that only the ions in the "nascent" state, as it were, are appreciably diffusible, while the nucleus is relatively a fixture. Again, the effect of secondary radiation is ignored.

12. *Conclusion.*—To decide between these hypotheses it is necessary to guide the X-rays by screens, suitably placed both on the inside and the outside of the apparatus; but these experiments are still in progress.

Here there is room only for a final remark. Whenever nucleation and ionization are associated as the outcome of any process (physical or chemical), the former is generated proportionally to the latter, in such a way that each is produced at its own rate depending on incidental conditions. This is best worked out with water nuclei. The subsequent life-history of the nucleation and the ionization is distinct, nuclei being surprisingly persistent, ions by contrast characteristically fleeting. Hence it seems to me to be best in keeping with all the data in hand, to regard the nucleation as the product which owes its growth or origin to the expulsion of the corpuscles representing the concomitant ionization. Ignition and high potential nuclei, X-ray and radiation nuclei in general, phosphorus and water nuclei, produced throughout in strictly dust-free air, all admit of this account of their occurrence and properties. There is no observable case of a process producing ionization without nucleation, although there are many cases of nucleation free from ionization.

It should be noticed that to produce the condensation on the X-ray air nuclei here in question, less than a twofold supersaturation is needed; whereas in case of condensation on ions the supersaturation prescribed is three to fourfold. The two views are not, therefore, mutually exclusive. Moreover, if initially, i. e., for short exposures and nuclei in the extreme state of fineness antedating growth, the nucleus is supposed to have ejected but one electron per nucleus (an assumption which in one form or another must be made in any explanation), the present view is in no way incompatible with J. J. Thomson's method of measuring the charge of one electron. Finally if a nucleus like that of phosphorus shows a tendency to grow continuously until it finally appears as part of a visible smoke, there may be continuous ejection of electrons within certain limits, as the growth matures. Electric conduction through a gas freighted with these nuclei would obey Ohm's law, as is actually the case for phosphorus.

Brown University, Providence, R. I.

Art. XII.—*Radio-active Measurements by a Constant Deflection Method;* by Howard L. Bronson.

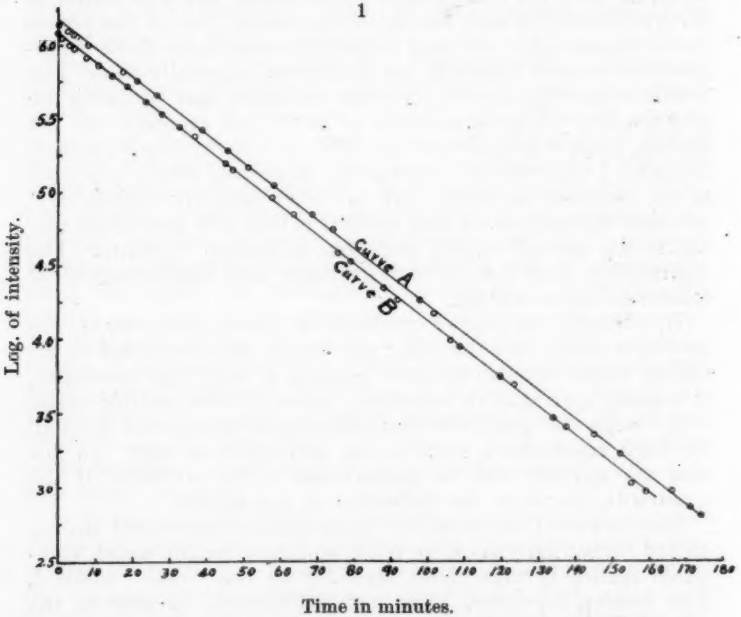
The ordinary method of using an electrometer for comparing ionization currents through gases has been to measure the rates of movement of the needle. The ionization currents are then proportional to these rates, if the following conditions are fulfilled: (1) that the capacity of the system remains constant, (2) that the deflection is proportional to the potential of the quadrants, (3) that the lag of the needle behind the potential is the same for different rates. In some cases these conditions are closely fulfilled, but in others, especially where the needle is moving rapidly, the last condition and probably the first are not. The introduction of additional capacity into the system, while it reduces the rate of motion of the needle, creates the added difficulty of comparing capacities, which not only takes considerable time but is never entirely satisfactory. Another difficulty with this method is that it is practically useless in the case of rapidly changing ionization currents. The desirability, therefore, of a more direct and rapid method of measurement is evident.

If, as usual, one pair of quadrants of the electrometer is connected to earth, and the other pair is not only connected to the testing vessel but also to earth through a very high resistance, it is easily seen that an ionization current in the testing vessel will charge the quadrants until the discharge current through the high resistance is equal to the ionization current. In this case the current will be proportional to the potential of the quadrants, that is, to the deflection of the needle.

Resistances of the order 10^{11} ohms made of pure amyl alcohol and of carbon on glass were tried, and gave results which compared favorably with those obtained by the "rate" method. The results, however, were not satisfactory, because in the case of the liquid resistance there seemed to be a variable polarization, whereas the resistance of the carbon was not perfectly steady. Professor Rutherford then suggested the possibility of using an ionization current in place of the conduction current through a high resistance. For this purpose he furnished a very radio-active bismuth plate from Dr. Sthamer of Hamburg. The activity of this plate was due to a deposit of the so-called radio-tellurium of Marckwald, which has such a long period of decay that it remains practically constant during any short experiment.

The bismuth plate was earthed and covered with a very thin sheet of aluminium to avoid contact potential difference. Another aluminium plate was placed parallel to this and connected to the same quadrants as the testing vessel, and the

whole was protected from air currents. The electrometer had a sensitiveness of about 150 scale divisions per volt, and with the plates 2^{cms} apart, the ionization currents were practically proportional to the deflections throughout the entire length of the scale (500 divisions). When the distance between the plates was increased to 2·7^{cms} the same deflection was produced by an ionization current only one third as large, that is, the sensitiveness of the apparatus was tripled; on the other hand, the current was proportional to the deflection for only about 150

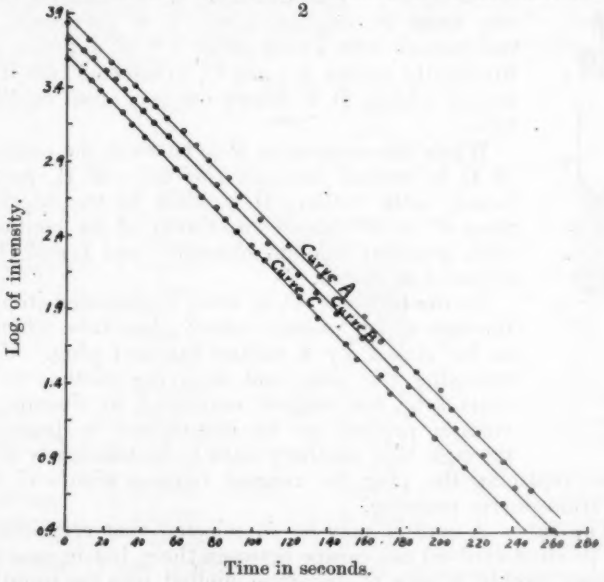


divisions. The currents measured varied from about 10^{-13} to 10^{-10} amperes.

The advantages of this method are obvious; deflections are independent of the capacity, measurements can be made over a large range without readjustment, and observations can be taken in as rapid succession as desired. In some cases observations were taken as often as once in five seconds. Figs. 1 and 2 show the accuracy which can be obtained by single sets of observations.

A and B, fig. 1, are two similar logarithmic decay curves of the excited activity of actinium, and should therefore be parallel. The time 0 was at least 20 minutes after the emanation was removed, so that the initial rise of the excited activity is not shown. The equation of the decay of any radio-active sub-

stance is given by Rutherford (Radio-activity, p. 258) as $\frac{I}{I_0} = e^{-\lambda t}$. From curve A, λ is found to be 0·0193, and from curve B, 0·0195, where the time is measured in minutes. The mean of these two values gives 35·7 minutes as the time required for the excited activity of actinium to decay to half value. This is a rather shorter time than was found by Debierne (Comptes Rendus, No. 138, p. 491), and verified by Miss Brooks (Phil. Mag., Sept., 1904). This smaller value, however, was confirmed by a large number of observations taken



by the "rate" method. The values thus obtained varied considerably, but their mean was about 36 minutes.

Fig. 2 shows three logarithmic decay curves for thorium emanation, which on account of its rapid rate of decay has been found so difficult to measure. By this method the observations for the three curves were taken in about thirty minutes. The value of λ obtained from curve A is 0·0129, from curve B is 0·0127, and from curve C is 0·0128,—a very satisfactory agreement for single sets of observations. A mean value of these λ's gives about 54 seconds as the time taken for the emanation to decay to half value, which agrees fairly well with the value 51·2 seconds recently obtained by C. Le Rossignol and C. T. Gimingham (Phil. Mag., July, 1904).

Macdonald Physics Building,
McGill University, Dec. 20, 1904.

ART. XIII.—*A Convenient Apparatus for Determining Volatile Substances by Loss of Weight;* by J. LEHN KREIDER.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cxxxiii.]

OF THE various forms of apparatus designed for the determination of volatile products of reactions, some are cumbersome and many require for their construction skill in glass-blowing. The apparatus here described is light and easily made from three test-tubes, modified and fitted as shown in the figure. The test-tube, A, is changed in no way from its original form; B is perforated, in the bottom, with a hole about 1^{cm} in diameter and fits tightly within A; and C, so selected that it fits loosely within B, is drawn out to a small capillary tube.

When the apparatus is to be used, the capillary of C is pushed through the hole of B, packed loosely with cotton; B is filled to the depth of from 6^{cm} to 8^{cm} (about two-thirds of its contents), with granular calcium chloride; and B and C are adjusted as shown.

To the test-tube, C, is fitted a one-holed stopper, through which passes a short glass tube which is to be closed by a rubber cap and plug. Upon removing the plug, and applying suction to the short tube, the reagent employed to liberate the volatile product to be determined is drawn up through this capillary until C is sufficiently filled. Upon replacing the plug the reagent remains within C, held by atmospheric pressure.

The tubes A and B may be so selected that very little of the product evolved can escape between them, but in case they fit very loosely, a ring of paraffine melted into the mouth of A, about B, by means of a hot iron or wire, seals the joint securely. A very convenient way to attach the paraffine is to melt it between A and another tube, which fits A, as does B, and may be removed by a turning motion, leaving the ring into which B will fit, and which then requires very little heating to make a tight joint. If care be used in taking apart A and B, at the close of an experiment, such a ring of paraffine remains in place and may be used many times without replacement, being remelted by a touch of the hot wire before every new experiment.

In making a determination, the substance under examination is weighed and placed in the bottom of A. The reagent to be employed, 10^{cm^3} to 15^{cm^3}, is drawn into C, and held there in the manner described. The test-tube A is slipped over B, and

this joint is sealed with paraffine, as has been shown. The apparatus is wiped, placed on the balance, and weighed.

Upon removing the cap from the small tube in C, the reagent runs from C into A. The volatile product is formed, is forced upward through the drying column of calcium chloride, and escapes through the annular space between B and C. When the action ceases, a current of dry air is forced through C, to drive all the volatile product from the apparatus, the cap is then replaced, and the whole placed on the balance to be weighed. The loss of weight represents the volatile product.

The following results show the accuracy which may be expected when carbonates are treated in the apparatus with dilute hydrochloric acid:

TABLE I.

	Taken. grm.	Found. grm.	Error. grm.
Calcium Carbonate.	0·2000	0·0879	−0·0001
	0·2000	0·0878	−0·0002
	0·2000	0·0879	−0·0001
	0·2000	0·0879	−0·0001
	0·5000	0·2197	−0·0003
	0·5000	0·2196	−0·0004
	0·5000	0·2194	−0·0006
	0·5000	0·2198	−0·0002
	0·5000	0·2197	−0·0003
	0·5000	0·2197	−0·0003
Barium Carbonate.	0·5000	0·1134	−0·0011
	0·5000	0·1137	−0·0005
	0·5000	0·1137	−0·0005
	0·5000	0·1136	−0·0006
Strontium Carbonate.	0·5000	0·1485	−0·0004
	0·5000	0·1486	−0·0003
	0·5000	0·1485	−0·0004

In Table II are included the results of some experiments made to determine the weights of hydrogen liberated by the action of magnesium and zinc, upon dilute hydrochloric acid.

TABLE II.

	Taken. grm.	Found. grm.	Error. grm.
Magnesium Metal.	0·1000	0·0087	+0·0003
	0·1000	0·0085	+0·0001
	0·1000	0·0084	±0·0000
	0·1000	0·0084	±0·0000
	0·1000	0·0083	−0·0001
Zinc Metal.	0·2000	0·0061	±0·0000
	0·2000	0·0062	+0·0001
	0·2000	0·0062	+0·0001
	0·2000	0·0060	−0·0001
	0·2000	0·0061	±0·0000

Determinations of the nitrogen liberated from urea, ammonium oxalate, and ammonium chloride, by action of sodium hypobromite, are given in the following table:

TABLE III.

	Taken. grm.	Found. grm.	Error. grm.
Urea.	0·1000	0·0469	+0·0003
	0·1000	0·0467	+0·0001
	0·1000	0·0467	+0·0001
	0·1000	0·0468	+0·0002
	0·1000	0·0467	+0·0001
Ammonium Oxalate.	0.1000	0·0204	+0·0007
	0·1000	0·0197	±0·0000
	0·1000	0·0198	+0·0001
	0·1000	0.0198	+0·0001
	0·1000	0·0196	−0.0001
Ammonium Chloride.	0·1000	0·0264	+0·0002
	0·1000	0·0265	+0·0003
	0·1000	0·0261	−0·1000
	0·1000	0·0263	+0·0001
	0·1000	0·0261	−0·0001

I wish to thank Prof. F. A. Gooch for his advice and kind assistance.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Canyon Diablo Meteorite.* — Moissan has made a new examination of a portion of this celebrated meteorite. When the mass was cut with a saw several very hard nodules were encountered which interfered greatly with the cutting operation. Upon dissolving a large mass of the meteorite, 53 kg., in hydrochloric acid, it was evident that the iron was not homogeneous, for it was attacked very irregularly. The hydrogen set free by this dissolving contained hydrocarbons, hydrogen sulphide, and hydrogen phosphide.

Certain samples taken from the exterior gave the following percentages: Iron, 95·64; nickel, 1·66. Iron, 95·26; nickel, 2·56. Iron 94·03; nickel, 3·61. Iron 96·31; nickel, 1·83. A sample of specific gravity 7·703, taken from the interior, gave: Iron, 95·370; nickel, 3·945; phosphorus, 0·144; insoluble in HCl, 0·260; silicon, traces; sulphur, traces; carbon, not determined.

A nodule, cut out with a chisel, gave the following analysis: Iron, 66·95; nickel, 1·93; cobalt, traces; sulphur, 22·15; phosphorus, 2·37; silicon, small quantity; magnesium, traces; carbon, 1·96.

The residue from dissolving 53 kg. in hydrochloric acid weighed 800 g. It consisted of a coarse powder, containing brilliant needles and cubes, both of which gave analyses corresponding closely to the formula P_2Fe_3, and contained only traces of nickel and carbon. In the residue which remained after treatment with concentrated hydrofluoric acid and boiling sulphuric acid, characteristic green hexagonal crystals of carbon silicide (carborundum) were found. This is the first time that this compound has been found in nature.

A part of the carbon in the meteorite escaped in the form of hydrocarbons upon dissolving it in hydrochloric acid, but the 800 g. of residue previously referred to contained 5·04 per cent of carbon. Five forms of carbon were noticed in this residue: A light, impalpable powder; jagged, slender fragments of a light color, which seemed to have been agglomerated by pressure; graphite, very rarely crystallized; smooth, black diamonds, abundant, but very small; transparent diamonds in the form of octahedrons with rounded edges.—*Comptes Rendus*, cxxxix, 773. H. L. W.

2. *Metallic Calcium.*—An examination of some of the chemical and physical properties of this metal has been undertaken by K. Arndt. The metal is now produced on the large scale by the electrolysis of fused calcium chloride, so that it is easily procured. Metallic calcium is ductile, and can be hammered and chiselled like brass, and it clogs a saw or a file. The fresh surface of the metal is brilliant, but it becomes yellowish rapidly, particularly in moist air. (The metal was formerly supposed to possess a

yellow color.) A piece of calcium reacts slowly with water on account of the difficult solubility of the hydroxide, but if a little hydrochloric acid is added, the evolution of hydrogen is violent. A sample of the commercial metal was found to contain 0·2 per cent of silicon and 0·3 per cent of aluminium with traces of iron. The hydrogen produced from it was very pure, and contained no appreciable amount of acetylene or other hydrocarbons. The specific gravity of the metal was found to vary considerably in different samples; a very pure specimen gave 1·52 as the result. In this investigation the melting-point was not very exactly determined, but it was near 800°. The metal begins to vaporize in a vacuum below its melting-point, and forms beautiful crystals which are free from silicon and aluminium. The vapor of calcium reacts very energetically—much more so than magnesium—with any residue of air that may be in the tube in which it is heated. In this way a very complete vacuum may be obtained from an imperfect one.—*Berichte*, xxxvii. H. L. W.

3. *The Use of Dried Air in Blast-furnaces.*—The employment of air dried by refrigeration, a process due to Mr. Gailey and applied at the Isabella Furnaces near Pittsburgh, has received considerable attention of late in the technical journals. The advantage attributed to the removal of the moisture from the air used for blast depends upon the fact that water is decomposed by incandescent carbon with the absorption of heat, and with the direct loss of carbon, by the reaction

$$C + H_2O = CO + H_2,$$

and it is claimed that a gain of 20 per cent is made in the efficiency of the fuel.

The process has been recently discussed by Le Chatelier, in France, from a scientific point of view, and he maintains that the gain in efficiency attributed to the process is about four times greater than the theoretical maximum obtained by calculation. He puts forward the view that the advantage is partly due to a possible effect of the dryness of the air upon the removal of the sulphur from the pig-iron, and supports this opinion by the results of experiments in which it was found that dry carbon monoxide free from hydrogen does not remove sulphur from heated calcium sulphide, while the gas when mixed with hydrogen removes it with considerable rapidity.—*Comptes Rendus*, cxxxix, 925.

H. L. W.

4. *Trisulphoxyarsenic Acid.* — McCay and Foster have prepared the salts

$$Na_3AsOS_3 \cdot 11H_2O,$$
$$NaSrAsOS_3 \cdot 10H_2O,$$
$$Ca_3(AsOS_3)_2 \cdot 20H_2O,$$
$$K_3AsOS_3 \cdot 7H_2O, \text{ and}$$
$$KBaAsOS_3 \cdot 7H_2O,$$

which represent a heretofore missing member, H_3AsOS_3, of a series of acids intermediate between H_3AsO_4 and H_3AsS_4, concerning

which most of our knowledge is due to McCay and his pupils at Princeton University, viz.,

$$H_3AsO_3S,$$
$$H_3AsO_2S_2, \text{ and,}$$
$$H_3AsOS_3,$$

These sulphoxy acids have not been isolated, and only the first two appear to exist in dilute solutions.

The trisulphoxyarsenates are usually colorless, crystalline, rather unstable compounds. The sodium salt is prepared by acting in the first place upon arsenic pentasulphide with a large excess of magnesium oxide in the presence of water, whereby the sulphide dissolves; then precipitating magnesium hydroxide by means of sodium hydroxide and removing it by filtration, adding alcohol to the liquid until a turbidity begins to form, and finally cooling to crystallization.—*Zeitschr. anorgan. Chem.* xli, 452. H. L. W.

5. *The Electrolysis of Solid Electrolytes.*—It has been found possible by Haber and Tolloczko to electrolyze solid barium chloride at a temperature about 400° below its melting-point. When barium carbonate had been mixed and fused with the barium chloride, carbon was produced at the cathode in quantities corresponding to the electric current employed, but when the barium chloride was free from carbonate, barous chloride formed quantitatively. In both cases the result may be assumed to be due to the reaction of metallic barium with the substances present. The experiments were conducted in nickel crucibles with careful regulation and measurement of the temperatures. Attempts to electrolyze sodium hydroxide were not successful when the substance was perfectly solid.—*Zeitschr. anorg. Chem.*, xli, 405.

H. L. W.

6. *The Determination of Fluorine in Wine and Beer.* — On account of the frequent use of sodium fluoride as a preservative, particularly for French, Spanish, and Greek sweet wines, and because of the poisonous effect of this preservative, which appears to have been established by the results of several investigators, Treadwell and Koch have undertaken the examination of various methods which appeared applicable to the determination under consideration.

No easy method for performing this difficult determination was found, but interesting results in regard to the accuracy of the standard methods, and the limits within which fluorine can be detected qualitatively, were obtained. A slightly modified apparatus for the determination according to Penfield's method is described and figured.—*Zeitschr. analyt. Chem.*, xliii, 469.

H. L. W.

7. *Direction and Velocity of Electric Discharges in Vacuum Tubes.*—Wheatstone in 1835, by means of a rotating mirror, arrived at the conclusion that this velocity was not less than 8×10^7 cm. per second; Plücker from observations in a magnetic field, concluded that the discharge emanated from the positive elec-

trode. Spottiswoode and Moulton found that the time which the positive electricity needed to traverse the tube was shorter than that which the negative electricity required to leave the cathode. They believed that the time occupied by a discharge to traverse a metallic conductor was much shorter than the time required through a discharge tube. J. J. Thomson took a discharge tube 15^m long, blackened it except at two points; threw an image of these two points on a cylinder. When the cylinder was at rest, the points or slits were directly over each other; when the cylinder was set in rapid revolution the images of the points separated. When the current was reversed, the images exchanged position. He concluded that the discharge was independent of the nature of the electrodes and always proceeded from the anode to the cathode, and that for a pressure of $0{\cdot}8^{mm}$ the velocity of the discharge was approximately half that of light. E. Wiedemann and G. C. Schmidt have shown that under certain conditions an apparent velocity of 200^m per second can be observed. Wüllner, Rhigi and others have noticed an extraordinarily slow velocity. On account of the divergence of results J. James has studied the question of the velocity in discharge tubes by means of the Abraham-Lemoine method of measuring small intervals of time. This method consists in employing changes in polarization of light in the magnetic field, or by electric stress. By these means a time interval of one hundred millionth of a second can be detected. James gives an analytical discussion of his employment of the method which he used to study the discharge of the electric spark in air, and also in a discharge tube. He found results which did not agree with those obtained by J. J. Thomson. They did agree, however, with those of Spottiswoode and Moulton. Further investigations are needed to determine whether from a study of the kind of illumination one can draw conclusions in regard to velocity.—*Ann. der Phys.*, No. 15, 1904, pp. 954–987.

J. T.

8. *Extinction of the Electric Spark.*—Wireless telegraphy and the study of N-rays give a great interest to the study of the electric spark. John Koch discusses conditions of residual charges of condensers and the fall of potential and other conditions which accompany or cause extinction. He concludes that the causes which lead to this extinction are purely electrodynamic and are identical with those connected with the dying out of the voltaic arc. The author concludes that Heydweiller's contention, that the development of energy is proportional to the time of discharge and independent of the current strength, is true only to a first approximation, when very great resistances are in the circuit.—*Ann. der Phys.*, No. 15, 1904, pp. 866–905. J. T.

9. *Exhaustion of Geissler Tubes by the Electric Current.*—It has often been noticed that the degree of exhaustion in Geissler tubes, and notably in X-ray tubes, is changed by long continuance of electrical discharges. At first the heat of the discharge increases the pressure and then there comes a lowering of the pressure

which indicates occlusion or absorbtion of the rarified gas in the glass walls of the tubes. EDUARD RIECKE has studied this soaking in effect in the case of nitrogen. He compares the effect of mere gas absorbtion with the absorbtion induced by the electrical discharges and estimates the connection between the strength of current and the resulting diminution of pressure.—*Ann. der Phys.*, No. 15, pp. 1003–1009. J. T.

10. *The N-rays.*—Authorities are still divided in regard to the existence of these rays. A. BROCA (Archives d'El Medicale, pp. 723–740, Oct. 10, 1904) points out that the observation of these rays is an extremely delicate one; in his own case it was six weeks before he could see the rays. He submitted himself to an elaborate course of training and he gives an account of the best way of studying the rays. He dwells upon the necessity of observing physiological conditions. Thus the eye must be adapted to almost completed darkness or at least to very feeble lights. The observer must be left with his mind free, all instrumental changes being intrusted to another. The effects due to heat must be borne in mind; for the physiological radiations can be entirely swamped by the heat effects. The two effects can be distinguished by the slight lagging (up to a few seconds) behind of the effect due to the N-rays, such lag being much greater in the case of the heat effect; and on the cessation of the action the difference of lag is even greater. The N-ray effect may also be distinguished by the different behavior when viewed normally, at 45°, and at grazing incidence.—*Science Abstracts*, Dec. 27, 1904.

It is stated in the Revue Scientifique of Nov. 26 that M. d'Arsonval has been able to reproduce the N-rays and to show that they are not due to heat. Mascart is stated to have observed the phenomena with D'Arsonval.—*Nature*, Dec. 15, 1904.

J. T.

11. *The Recent Development of Physical Science;* by WILLIAM CECIL DAMPIER WHETHAM, M.A., F.R.S., Fellow of Trinity College, Cambridge. pp. 445, 8vo. Philadelphia, 1904 (P. Blakiston's Son & Co.).—At a time like the present, when the public in general is more than ever before keenly alive to the progress made in science, it is most useful to have the topics of immediate interest presented in a form so simple and clear that anyone who is well grounded in the fundamental principles can gain a good understanding of what is being done. This is eminently true of the book in hand, which, in a series of eight chapters, gives an admirable presentation of some of the subjects in physics, which are just now of greatest interest and in which progress has been and is being made. The author has a thorough command of his subject, and has also had the advantage of assistance from various specialists in the different lines. Some of the subjects dealt with in the eight chapters are: the liquefaction of gases, fusion and solidification, solution, electric conduction through gases, radio-activity, atoms and ether. The frontispiece is a representation of the well-known statue of Newton, and portraits of Lord

Kelvin, J. J. Thomson, van't Hoff, with other illustrations, are scattered through the volume.

12. *Outlines of Physiological Chemistry;* by S. P. BEEBE and B. H. BUXTON. 195 pp. New York, 1904 (The Macmillan Co.). —The title of this little book is perhaps somewhat misleading if it gives the impression of any systematic review of the subject. The aim of the authors is rather to deal with the theoretical side of the various chemical questions arising in physiology, and to explain the nature of the more important reactions with which the student has to deal. The book includes chapters on the theory of solutions, and on the chemistry of the carbon compounds; the more distinctly physiological part is almost entirely devoted to the proteids and to enzyme action. The current theory of immunity is also outlined. L. B. M.

I. GEOLOGY AND MINERALOGY.

1. *Geological Survey of Canada*, ROBERT BELL, Acting Director. Annual Report, vol. xiii, 1900, 747 pp., 8 maps, 15 pls. —The Canadian survey reports are always of interest because of new territory explored and the geological reconnoissance which is being carried on. The present report shows that a great amount of work in several lines is being accomplished at small expense. The principal papers bound in the volume are: Exploration of East Coast of Hudson Bay and Geology of Nastapoka Islands, by A. P. Low; Parts of Saskatchewan, Athabaska, and Keewatin, by J. B. TYRRELL, and also by D. B. DOWLING; Basin of Nottaway River, by ROBERT BELL; Geology and Petrography of Shefford Mountain, Quebec, by J. A. DRESSER. These papers have been previously issued separately.

Dr. Low's investigations show that the land about Hudson Bay is now 700 ft. above the level during the ice age. He finds no evidence of present elevation. (For the contrary view see article by Dr. Bell in Geol. Soc. Am., 1895.) The key to the stratigraphic problems in the Cambrian, which shows buckling and nearly horizontal movement, is found in the contraction of intruded granite masses. "The contacts of the bedded rocks and granites are usually unconformable and appear to be due to a nearly horizontal movement of the bedded series subsequent to the intrusions of the granite, due to pressure acting from outside the great areas of granite. This series of sedimentary rocks being close to the surface broke as does ice upon the shore when pressed from seaward and piled cake on cake not only upon unyielding granite but upon themselves."

2. *The Iowa Geological Survey*, SAMUEL CALVIN, State Geologist: Vol. xiv, Annual Report of 1903, 655 pp., 38 pls., 132 fig.— The last annual report of the Iowa Geological Survey is chiefly economic in character, and in addition to the annual statistics contains an extensive treatment of clays and clay products in general with special reference to the Iowa deposits. At the present time

the clay products of Iowa stand second in value only to the output of coal. The survey is also collecting data relative to the artesian waters in Iowa, and plans to publish a report on the same. The U. S. Survey has completed the topographical work in northeastern Iowa, so that the state survey will now work out the details of geology in that section. An investigation is in progress regarding the coals of Iowa, their occurrence, physical and chemical characteristics, geological and geographical relations.

3. *Glaciation in South Africa.*—At the October meeting of the Geological Society of South Africa, Mr. M. E. FRAMES describes the geology of the Amsterdam Valley. Part of the village of Amsterdam is built on a glacial moraine of undoubted Dwyka structure and age. As had been shown before, a direction of glaciation which resulted in the deposition of the Dwyka is proved to have been from the north. This view has recently received support from the fact that a characteristic porphyritic rock which is found in the conglomerate at Amsterdam has been discovered *in situ* forty miles to the north. A large outcrop of this rock has been discovered on Bonnie Braes farm near Oshoek.

4. *Ueber Untersilur in Venezuela;* von Dr. FR. DREVERMANN. Neues Jahrb. f. Min., Geol. u. Pal., 1904, pp. 91-93, pl. x.—This little paper is of great interest in that it proves the occurrence of lower Paleozoic deposits on the north side of the Venezuelan-North-Brazilian shield. Engineer Klein, in traveling from Caracas over Valencia to Puerto Cabello, collected a few fossils which Dr. Drevermann thinks are indicative of Lower Silurian age. These specimens are *Calymmene senaria* like those from Cincinnati, Ohio, and *Orthoceras* cf. *olorus* Hall. As no Ordovician formations are known in northern South America the reviewer raised the question—Are these fossils probably of Silurian age? With this in view he addressed the author of the present paper, under date of August 3, 1904, as follows: "The *Calymmene* is nearer to *C. niagarensis* than to *C. senaria* (= *C. callicephala*). . . . As for *Orthoceras* cf. *Volorus* it may be one of several of our Niagaran annulated forms. Its size is so large that I think it rather a Niagaran species.

"On the other hand, in Brazil on the south side of the old land mass there is good Upper Silurian, which as you know was described by Clarke. All in all I feel that the Venezuela fossils are of Upper Silurian age." On October 25 last, Drevermann replied as follows: "I have had another opportunity to compare the *Calymmene* of Venezuela with the North American material kindly sent me by you. An identity with *C. niagarensis* I cannot agree to in spite of the extraordinary similarity heightened by the fact that both examples are preserved in dolomite. The lower lobe of the glabella of the Venezuelan specimen is much larger than in *C. niagarensis* and the latter in this respect reminds one of *C. callicephala* (respectively *C. senaria*). The head of *C. niagarensis* is also considerably more arched. On the other hand, the South American example agrees with *C.*

niagarensis in regard to the distance of the facial suture from the posterior margin.

"The certainty that the specimen is of Lower Silurian age is therefore shattered; it may be that it is Upper Silurian and in this case it would be according to your view about Niagara. The Orthoceras is unfortunately not diagnostic." C. S.

5. *Devonian Fauna of Kwataboahegan River;* by WILLIAM ARTHUR PARKS. Rept. Bureau of Mines, 1904, Pt. I, pp. 180–191, pls. 1–8.—This paper is of much importance because it gives one a clear understanding of the facies of the Devonian fauna found on the west side of James Bay, heretofore a rarely visited region. The reviewer has elsewhere discussed this fauna, and before Professor Parks's much larger list was made known (Amer. Geol., Sept., 1903, pp. 153, 154). He then stated that the "fauna as listed by Whiteaves shows unmistakably that their age is about that of the Corniferous (Onondaga)."

The reviewer has enjoyed the privilege of studying the collection belonging to Professor Parks; hence some of the species here cited appear under other names than in the work reviewed. The following list is not complete, only the more significant species being mentioned: *Syringopora nobilis, S. perelegans, S. hisingeri, Diphyphyllum simcoense, Phillipsastræa* (?) *gigas, P.* (?) *verneuili, Crepidophyllum archiaci, Favosites basaltica, F. hemisphæricus turbinatus, Romingeria umbellifera, Heliophyllum exiguum, Stropheodonta demissa, S. crebristriata, Strophonella ampla, Chonetes lineata, Spirifer grieri, S. unicus* (the Onondaga form of the Oriskany *S. arenosus*), *Meristella nasuta, Atrypa reticularis, Amphigenia elongata undulata, Conocardium cuneus trigonale, Callonema bellatulum, Platystoma lineatum, Pleurotomaria lucina, Bellerophon pelops, Orthoceras tantalus, O. thoas, Calymmene platys, Dalmanites archiops, D.* (*Synphoria*) *stemmatus* (an Oriskany species), and *Phacops cristata.*

The author states: "It would also appear that the organisms denote an age comparable with the bottom of the Upper Helderberg. In some cases the assemblage would denote the Oriskany." These conclusions are undoubtedly correct, for the Onondaga as seen about Decewville, Ontario, has a large percentage of Oriskany species, but has not *Spirifer unicus.* The latter, however, occurs in the Onondaga not far to the southeast, in Erie county, New York. In general the James Bay Devonian holds the horizon of the Onondaga and has many of the diagnostic species of the Schoharie grit and Onondaga, and at least one of the very characteristic Oriskany brachiopods.

The former conclusion of the reviewer "that the faunal facies is more that of the Mississippian type than any other known" is, through this collection of Professor Parks, brought into closer and more decided harmony with the typical Onondaga of New York. It is clearly established that this fauna did not continue westward into the Manitoba-Athabasca region, as here are known

formations somewhat younger, with the *Stringocephalus* fauna of the Euro-Asiatic type. C. S.

6. *Ueber den Bau und die Organisation der Lyttoniidæ Waagen;* by Dr. F. NOETLING. Verh. Deutsch. Zool. Gesellsch., 1904, pp. 103–122.—On the basis of excellent etched material, this author here revises the remarkable brachiopod family Lyttoniidæ, the genera *Oldhamina* and *Lyttonia*, and the species *O. decipiens* and *L. nobilis*. In 1901 Noetling. (Neues Jahrb., Beil.-Band xiv, p. 452, foot-note) thought that *Oldhamina* was a "remarkable type of Bryozoa," and because of the similarity of the name to *Oldhamia* he proposed to change it to *Waagenopora*. Under the rules of nomenclature, this change of name can not be made. In the present paper, Noetling says nothing of this proposed name or of his former view as to the nature of these peculiar brachiopods. Other authors have regarded *Oldhamina* as a gastropod and *Lyttonia* as fish teeth, but Noetling's work makes it very clear that we are here dealing with degenerate brachiopods related to *Strophalosia* by the concavo-convex form of the valves and especially by the cardinal process of the dorsal valve, the dental plates, and the fixed or cemented nature of the ventral valve.

The author correctly states that these forms can not be brought into relation with terebratuloid types like *Megathyris*, but does not seem to have noticed the conclusion of Beecher and Schuchert that the affinities of these brachiopods are near the Thecidiidæ as defined by the latter authors—forms closely related to the strophomenoids. Noetling's work makes it now necessary to remove the Lyttoniidæ from the family Thecidiidæ and to associate them as a family with the productoids. The family Lyttoniidæ had its origin probably in *Strophalosia* in Upper Carboniferous time, and is to be regarded as an aberrant and degenerate branch of that genus.

According to Noetling, the great number of so-called "lateral septa" of the ventral valve may be regarded "as supports for the lobes of the dorsal shell," or he thinks "that both median stems of the mantle sinus lay in the space on both sides of the median septum. From the latter came the side branches and continued in form as broad, flat, vascular strands between the lateral lamellæ." The reviewer does not regard these markings as due to the mantle sinus nor as supporting septa, but believes that they are caused by the lobations of the brachia. In the productoids the brachia are in the early ptycholophus or latest schizolophus stage, as may be seen by the reniform markings in many species, yet in the Lyttoniidæ, owing to the progressive elongation of the shell, the brachia are longer and much more numerously lobed, with the lobes directed laterally. Some of this evolution is shown in the oldest *Oldhamina* (?) of the Carnic Alps, described by Schellwien, having but six anteriorly directed lobes; and in the *Keyserlingina* with the same number of laterally directed lobes, recently described by Tschernyschew. In the

most recent *Oldhamina* and *Lyttonia*, however, there are from fourteen to forty lobes. The latter represent the highest expression of the ptycholophus stage of brachial development in brachiopods (see Beecher, Bull. U. S. Geol. Surv., No. 87, 1897, p. 108). In the dorsal valve the lobes of the brachia lie between the elevations, while the so-called lateral septa of the ventral valve lie between the recurved bands of each brachial lobe.

Noetling thinks that *Oldhamina* lived with the "dorsal valve directed downward and probably partially buried in the mud." This is an anomalous mode of life for any brachiopod other than *Lingula*. The early cemented condition of these shells indicates that *Oldhamina* lived like other related forms, i. e., with the ventral valve underneath.

The Lyttoniidæ are known in India only in the Upper Permian, i. e., in the Middle or Upper Productus-limestone. They are also known in the Himalaya; at Loping, China; Rikuzen, Japan; near El Paso, Texas, and in Nevada. The occurrence of the older forms has been mentioned above.

Noetling concludes: "Against one's will the impression is made that shortly before extinction the Paleozoic brachiopods once more attained a great development. Probably, however, on account of this accelerated development, they held in themselves the cause for their early extinction, as shown by the aberrant, weak, and possibly even degenerate forms." It is one of the remarkable occurrences that at the close of the Paleozoic, in different stocks of the Strophomenacea, aberrant forms became numerous. These genera are *Keyserlingina*, *Oldhamina*, *Lyttonia*, *Loczyella*, *Tegulifera*, *Richthofenia*, *Proboscidella*, and *Scacchinella*. C. S.

7. *The Tower of Pelée: New Studies of the Great Volcano of Martinique;* by ANGELO HEILPRIN. Pp. 62, 4to with xxii pls. Philadelphia, 1904 (J. B. Lippincott & Co.).—The results of the studies by the author of the volcanic phenomena of Martinique have already been partly made known in several valuable papers which he has published. The present work contains much interesting descriptive matter and some important suggestions concerning the nature and cause of volcanic action, but its chief interest lies in the description and explanation of the remarkable monolith which rose from the top of Mont Pelée until nearly a thousand feet in height. In spite of repeated shattering and breaking it maintained by constant upward growth a great height for many months before it disappeared. This tower of rock Professor Heilprin regards as the solidified plug of lava filling the conduit of the volcano from a previous active stage which was driven up and out by the renewal of volcanic activity which has recently taken place, and not as the lava of the present epoch, cooling and solidifying as it is forced upward. The facts and arguments favoring this view are presented in detail, since the latter idea has been held by other investigators. The volume is an important and timely contribu-

tion to volcanology and is embellished with many beautiful half-tone plates, reproductions of the author's photographs. L. V. P.

8. *Die Jüngeren Gesteine der Ecuatorianischen Ost-Cordillere*, von F. TANNHÄUSER. Wilhelm Reiss, Ecuador, 1870–1874, Petrograph. Untersuch. II, Lief. II, pp. 119–186, 4°, 1904 Berlin. —This is a continuation of the investigation by Reiss of the rocks collected by him in the Andes; this investigation has now been carried on for many years in the mineralogical institute of the University of Berlin under the direction of Professor Klein, as noticed in previous issues of this Journal.

The rocks described are from the Cordillera de Pillaro as far as Sangay, from Azuay and from a part of the Cuenca basin, and comprise the lavas of the great volcanoes of Tunguragua, Altar, Sangay and Azuay. They are nearly all varieties of dacites and andesites whose petrographic characters are given in detail accompanied by a number of analyses. L. V. P.

9. *Die Älteren Gesteine der Ecuatorianischen Ost-Cordillere*, von F. VON WOLFF. Ibidem Lief. III, pp. 189–304, 1904.—In the work mentioned in the foregoing notice only the geologically recent lavas are considered. The petrographic investigation of the region named above is completed in the present memoir, which gives the results of researches made on the older rocks. These comprise gneisses, amphibole schists, diabases in various stages of dynamic metamorphism, mica schists, granites, gabbros, porphyries of various kinds, etc. These have been carefully studied and correlated and in a number of cases analyzed. These two works add much to our knowledge of Andean rocks and petrology. L. V. P.

10. *Ueber die Chemische Zusammensetzung der Eruptivgesteine in den Gebieten von Predazzo und Monzoni*, von J. ROMBERG. Anhang. Abhandl. d. K. Preuss. Ak. Wiss. Jahr, 1904, pp. 135, 4°, Berlin.—In this work the author, in addition to giving a number of new analyses of the rocks of this classic locality, which have been made in connection with his researches by Drs. M. DITTRICH and R. POHL, has assembled all those previously made by other investigators. They are arranged and discussed according to the chemical classification proposed by Osann. The recent work of other geologists in this region is also taken up and critically examined and many dissenting opinions expressed. The new analyses have evidently been well and carefully executed and add much information to our knowledge of this complex and interesting group of igneous rocks. L. V. P.

11. *Heptorit, ein-hauyn-monchiquit aus dem Siebengebirge am Rhein*, von K. BUSZ. Neues Jahrb. f. Min., Bd. II, 1904, pp. 86–92.—This new variety of monchiquite occurs as a narrow dike on the boundary between trachyte and Devonian graywackes and in the hand specimen appears like a fine-grained basalt. The microscope shows it to consist of basaltic augite, a relatively large amount of brown hornblende in fine needles and well crystallized violet-blue hauynite. These minerals lie in a colorless

base which is assumed to be glass; whether it may not be wholly or in part analcite is not mentioned. Occasional laths of labradorite also occur and in places the rock holds the large masses of olivine often seen in basaltic rocks. An analysis gave the following results:

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O
43·92	1·78	17·62	4·05	3·94	13·07	8·16	2·84

K_2O	H_2O	SO_3	P_2O_5	Cl	Total
1·33	2·82	0·47	0·15	0·22	= 100·37

This appears to be a well-defined type of this small but interesting group of igneous rocks. The name is the translation into Greek of the Siebengebirge where it occurs. L. V. P.

12. *Die Kristallinen Schiefer*, I, *Allgemeiner Theil*, von U. GRUBENMANN. Pp. 101, 8vo, 2 pls. 1904, Berlin (Bornträger Pub.)—The author states that this work, which is a summation of his lecture course upon this subject, is an attempt to explain in accordance with physical and chemical principles the origin and characteristic properties of the crystalline schists. He begins with a description of the material from which the schists are formed, giving the origin and characters of the sedimentary and igneous rocks, so far as these pertain to the subject. Next the various factors of metamorphism are dealt with, the effects of solutions, of high temperatures, of pressure, etc. After this the results of these agencies in the production of different minerals, structures, textures, etc., are discussed and the work concludes with a short, general account of the geological occurrence of the crystalline schists. It is clearly and simply written and the student and teacher of petrography will find much in it that is interesting and suggestive. It is inferred from the scope and title of the book that it is only the introductory portion of a larger descriptive work. L. V. P.

13. *Yttrium and Ytterbium in Fluorite.*—W. J. HUMPHREYS, as the result of a spectroscopic examination of samples of fluorite from many localities in all parts of the world, shows that the rare element yttrium is distinctly present in most cases while a considerable number contain also ytterbium. The specimens found to be richest in these elements were from Amelia Court House, Virginia, Llano County, Texas and Corocoro, Bolivia. The two localities first mentioned afford a number of rare mineral species which were also found to contain yttrium and often in addition ytterbium. It is interesting to note that the three samples mentioned proved to be exceptionally sensitive to the effect of heat in producing phosphorescence; as noted by the author some years since, a fluorite from Amelia Court House became luminous simply from being held in the hand for a few minutes.—*Astrophys. Journal*, xx, 266.

14. *Hamlinite from Brazil.*—The rare mineral species hamlinite, thus far only known from Maine, as described by Penfield, has been identified by Hussak in the diamond-bearing sands of the Serra de Congonhas, Diamantina, Brazil. It occurs sparingly

in colorless to rose-red or yellow crystal and cleavage fragments: the faces *c*, *r* and *f* were identified and the angles found to agree with the measurements of Penfield. The specific gravity is 3·254 to 3·281. A qualitative examination by Florence proved the Brazilian mineral to be a hydrophosphate of aluminium and strontium without barium or fluorine, but probably containing a small amount (2 p. c.) of alkalies.—*Ann. Nat. Hofmuseums*, xix, 93, 1904.

III. Miscellaneous Scientific Intelligence.

1. *Publications of the Yale Observatory.*—The Yale Observatory has recently issued a Report of the Director, Dr. W. L. Elkin, for the years 1900–1904. In regard to the work of 1903–1904, he states: "During the past year the heliometer has been in active operation, Dr. Chase having devoted himself with great energy and self-sacrifice to the completion of the stellar parallax research we have been engaged upon for the past ten years. This now may be said to have finally reached a point where the observations may be suspended and our energies entirely given to their reduction. Mr. Smith has completed the new series on the parallax of Arcturus and has begun a series on the parallax of the Pleiades.

The meteor apparatus was put in use during the November epoch and a few trails secured. Dr. Max Wolf of Heidelberg, Germany, has kindly forwarded to us his meteor photographic trails of the Perseid epoch and those which seem to be true Perseids have been measured by Miss Palmer. Miss Palmer and Miss Newton are still employed on the index catalogue to the Bonn Durchmusterung. The time service has been maintained efficiently by Messrs. Chase and Smith."

The concluding portion of Volume I of the *Transactions* has also been published. This includes the Preface and Parts VII and VIII, pp. 335–390. These parts are devoted to a Revision of the first Yale triangulation of the principal stars in the group of the Pleiades by Dr. W. L. Elkin; and a second Determination of the relative position of the principal stars in the group of the Pleiades by Mason F. Smith.

2. *Publications of the Yerkes Observatory, Vol. II, 1903.* Chicago, 1904 (University of Chicago Press).—This volume, also issued as Vol. VIII of the first Series of the Decennial Publications of the University, contains a series of seven articles, on work done at the Yerkes Observatory; their titles are as follows: Measures of double stars in 1900 and 1901, by S. W. Burnham; micrometrical observations of Eros during the opposition of 1900–1901, by E. E. Barnard; recent rigorous methods of treating problems in celestial mechanics, by F. R. Moulton; radial velocities of twenty stars having spectra of the Orion type, by E. B. Frost; spectra of stars of Secchi's 4th type, by G. E. Hale, F. Ellerman and J. A. Parkhurst; astronomical photography with

the forty-inch refractor and two-foot reflector, by G. W. Ritchey, accompanied by 26 plates, giving beautiful photographs of the moon's surface, star clusters, nebulæ, and other points; and lastly, the orbit of the minor planet (334) by Kurt Laves.

3. *How to Know the Starry Heavens, a Study of Suns and Worlds;* by EDWARD IRVING. Pp. xvi, 313, with charts, colored plates, diagrams, etc. New York, 1904 (Frederick A. Stokes Co.). —The present volume is one of a series planned by the author which are to deal with the sciences of Astronomy, Geology, Biology and Sociology. It is a very liberally illustrated account of the celestial universe, with the subjects presented in clear, popular, and often colloquial style, which must certainly appeal to the class of readers for which it is intended. Some of the word-illustrations introduced are novel and ingenious, and will help to an understanding of a somewhat difficult subject. The next volume to appear will deal with the earth, from its nebulous birth to the advent of man, and will be entitled: "How to Know the Earth's History."

4. *The Jefferis Mineral Collection.*—It is announced that the Carnegie Museum, Pittsburg, Pa., has purchased the Jefferis collection of minerals; it is to be known in perpetuity as "The W. W. Jefferis Mineral Collection of the Carnegie Museum." It owes its existence to the active work and liberal expenditure by Mr. Jefferis begun some seventy years ago, and now ranks as one of the finest private collections of minerals in America. Living in West Chester, Chester county, Pa., he had unusual opportunities of collecting choice specimens from the ancient gneisses, serpentines and limestones, as well as from the trap rocks of eastern Pennsylvania, New Jersey and New York. He also visited northern New York, Canada and Europe; and carried on extensive exchanges with other collectors all over the world.

Mr. Jefferis, although primarily a collector, was also a discoverer and contributor to science. A number of new minerals were discovered by him and in addition he aided largely in extending the distribution of known minerals and in furnishing material for the reëxamination of old or poorly known ones. Dana drew largely from Mr. Jefferis' notes and specimens, some of which were figured in his "System of Mineralogy"; Genth's "Mineralogy of Pennsylvania" was also indebted to Mr. Jefferis' labors in the field.

5. *The Chemical Engineer.* — A new monthly journal of practical, applied and analytical chemistry was started in November, 1904, under the above title. It is published by The Chemical Engineer Company, Allentown, Pa., at $3 a year. The first number contains articles on the Valuation of Coal for Steaming Purposes, on Tests for Wood Paving, with others on subjects less directly technical.

OBITUARY.

DR. BENJAMIN W. FRAZIER, Professor of Mineralogy and Metallurgy at Lehigh University, Bethlehem, Penn., died on January 4 at the age of sixty-three years.